NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: MM(JWH/bd)

MAY 7 1971

MEMORANDUM

TO: Distribution

FROM: NASA Director of Life Sciences

SUBJECT: Transmittal of "A Biomedical Program for Extended Space Missions, Volume II"

The attached document was prepared for this office by members of the NASA/MSC, Office of Medical Research and Operations, and the Bellcomm Life Sciences Group.

We believe it contains interesting and useful material, and are therefore transmitting it for your information and appropriate use in program planning.

J. W. Humphreys, Jr.

J. W. Humphreys, Jr., M.D.

Encl: "A Biomedical Program for Extended Space Missions, Volume II" Bellcomm Memorandum No. B71 05018

Bellcomm

955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

B71 05018

date: May 7, 1971

to: Distribution

from: Dr. L.F. Dietlein (MSC/DA), B.A. Gropper, Dr. W.E. Hull (MSC/DA), A.N. Kontaratos, R.S. Mach*, R.E. McGaughy

subject: A Biomedical Program for Extended Space Missions, Volume II - Case 236

ABSTRACT

This is the second volume of a two-part study defining guidelines for a manned space flight biomedical-behavioral program. The first volume** identified specific problem areas and outlined the research and development activities needed to solve them. The present volume establishes task priorities and outlines strategies for meeting the goals of long-term support of man in space.

Consideration of the array of man-task-environment factors and their interactions suggests that highest priority studies should be conducted in the following areas:

1. The effects of weightlessness on circulatory and musculoskeletal phenomena including neural and humoral control processes.

2. An optimal set of physiological indices for evaluating crew stress status.

3. Monitoring and evaluating individual emotional adjustments, interpersonal relations, and task performance.

4. The effect of orbital flight on biological periodicities, including possible shifts in diurnal physiological rhythms.

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*Presently at the Department of Psychology, University of Colorado.

**"A Biomedical Program for Extended Space Missions", Directorate of Medical Research and Operations, NASA/MSC, May 1969".

In addition, considerations of safety and cost effectiveness for individual missions dictate the following development strategies:

1. Integration of biomedical-behavioral observations within the mission protocol. The results must be made available in real or near-real time, to guide key decisions and improve the safety of the ongoing mission.

2. Crew performance assessment should be carried out by instrumentation of key engineering and scientific systems, supplemented by audio and visual monitoring of personal and interpersonal behavior.

Both of these strategies will benefit the ongoing mission by increasing safety and decreasing interference with other mission objectives.

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MEMORANDUM FOR FILE

INTRODUCTION

Before NASA can embark on major manned programs of exploration and orbital operations involving long-duration space flight, man's survival and usefulness in space must be assured. This can only be done through a careful quantitative study of man's physiological, psychological, and social adjustments as they occur in flight. Measures for the overall status of the crew at a given time during flight must be established, and an accurate time profile of the adaptation of men to space conditions must be developed. We must find out whether the long-term adjustments a man makes in space eventually lead to a new stable level, or whether continual adjustments cause him to eventually exceed his reserve capacity for meeting stress. Even if man does successfully adapt to space conditions, the return to earth involves an additional adaptive change which we know very little about. Avoiding gross crew incapacitation during the flight and getting the astronauts safely back to earth have been the focus of attention to date.

Several authoritative scientific advisory groups (Refs. 1, 2, 3, and 4) have stated that development of adequate knowledge of man's characteristics and potential for safe and effective performance in space requires a broad program of multidisciplinary research efforts. Man's psychophysiological responses to space flight conditions must be sufficiently understood and spacecraft habitability adequately enough designed so that any healthy person can:

a. complete prolonged missions without significant physiological degradations or performance decrements during the flight;

b. withstand the dynamic stresses of reentry without injury, loss of functional capability, or excessive discomfort; and

c. re-acclimatize to normal earth conditions, with no long-term residual effects after the flight.

To delineate the nature, time-course, severity, and consequences of changes already observed, and of other possible effects as yet undetected, the program should afford a broad coverage of many interrelated areas, including: cardiovascular physiology, respiratory physiology, musculoskeletal physiology, endocrinology, neurophysiology, metabolic physiology, hematology, immunology, physiological psychology, social psychology, and task performance.

This report is the second volume of a two-part study defining tentative guidelines for a biomedical/behavioral program for manned space flight. The first volume, "A Biomedical Program for Extended Space Missions", was released by the Directorate of Medical Research and Operations, NASA/MSC, in May, 1969. It identified specific problems and corresponding research and development activities for obtaining the knowledge and operational techniques necessary for long-term support of man in space.

The present volume identifies task priorities and outlines research strategies for meeting those goals. It does not provide a list of mission-specific payloads inasmuch as no long-range manned flight program has been defined beyond Skylab.

Material within this volume is organized in three main sections: Crew Physiology, In-flight Behavior and Performance, and Program Planning Guidelines. The first and second sections attempt to answer three basic questions within their respective areas:

1. What information do we need in order to plan and carry out manned space flights of long duration with a high degree of confidence?

2. Since all information is not necessarily of equal importance, what are the highest informational priorities?

3. What are the appropriate strategies for obtaining this information?

The third section attempts to relate the material in the two preceding sections to future manned space flight activities, and identify operational guidelines that will provide biomedical and behavioral support of human crews during prolonged scientific and technical missions.

Three appendices provide more detailed background coverage of present understandings of the fundamental biomedical and behavioral systems interrelationships upon which this report has been based.

Appendix A attempts to provide a broad first-order descriptive model of how human beings interact with their environment. The functional relations among man's biological and psychological characteristics must be accommodated in the design and conduct of complex multi-man long-duration missions. Future success will depend on how adequately we can handle these complex interdependencies. The safe and effective support of future manned systems depends on our abilities to refine present state-of-the-art diagnostic and monitoring methods, so as to permit large-scale modeling and real-time integrated support beyond our present capabilities.

Appendix B presents a broad review of physiological processes in terms of how the body's major subsystems function and how they react to the inflight stressors investigated to date.

Appendix C summarizes the factors to be considered in the planning of an artificial gravity experiment.

CREW PHYSIOLOGY

1. REVIEW OF FLIGHT RESULTS

Prior to manned spaceflight, plausible but untested theories predicted catastrophic failures of various physiological functions in organisms suddenly exposed and maintained in a gravity-free environment. Orbital experience refuted these theories; but by the end of the Mercury Program positive evidence was available to indicate the crewmen were experiencing significant physiological changes in flight.

Studies were conducted during the Gemini Program to determine the extent of the flight-related effects first noticed late in the Mercury Program. Although there may have been reactions that were not detected, these studies demonstrated that all identifiable changes were completely reversible for flights lasting up to two weeks. These medical findings are summarized in Table 1.

Regarding the physiological effects of weightlessness, ground-based evidence suggests that cellular processes are not influenced by gravity. Survival of single cell organisms in the terrestrial environment does not depend upon a particular preferential orientation of their anatomical structure with respect to the gravity vector. Additionally, because of the buoyancy provided by the cytoplasm, all cellular components experience a subgravity force between 0.1 and 0.3g depending on their molecular densities. More important, however, US and USSR experiments conducted during actual space flight have shown that cells exposed to zero-g for as much as a few days divide, differentiate and develop normally (Ref. 5). These latter findings are extremely important for yet another reason.

It is well established that all terrestrial cells share the same fundamental biochemical processes and obey the same physical laws. Additionally, it is also known that the metabolic and reproductive rates of cells in vitro are much faster than those of cells in vivo. Consequently, since cells in vitro replicated many times in orbit, one can argue that the observed in-flight responses of isolated cells to weightlessness indicate, on an accelerated time scale, the type of responses expected from cells within the intact human organism. In other words, it does not appear probable

TABLE I

STATUS ASSESSMENT OF MAJOR HUMAN SYSTEMS

AFFECTED SYSTEM	NATURE AND TIME OF OBSERVATION	PROBABLE PRIMARY CAUSE	DEPTH OF STUDY
MUSCULOSKELETAL	POSTLANDING 1. MINIMAL LOSS OF BONE DENSITY 2. MINIMAL LOSS OF MUSCLE TISSUE 3. REDUCED EXERCISE CAPACITY	WEIGHTLESSNESS AND RELATIVE INACTIVITY	MODERATE
ENDOCRINE	INFLIGHT (WELL INTO MISSION) APPARENT DEPRESSION OF STRESS HORMONES POSTLANDING ELEVATION OF STRESS HORMONES	INACTIVITY, PSYCHIC STRESS MECHANICAL STRESS DURING AND FOLLOWING REENTRY	MINIMAL
EYE, NOSE, THROAT, SKIN, BODY MASS	INFLIGHT 1. EYE IRITATION 2. NASAL STUFFINESS 3. THROAT HOARSENESS 4. SKIN DRYNESS, DANDRUFF 5. MODERATE LOSS OF BODY WEIGHT	OXYGEN ATMOSPHERE WEIGHTLESSNESS AND RELATIVE INACTIVITY	MODERATE
CARDIOVASCULAR	INFLIGHT INCREASED HEART RATE DURING LAUNCH, EVA, AND REENTRY POSTLANDING 1. SHORT LASTING INCREASED HEART RATE 2. REDUCED TOLERANCE TO CHANGES IN POSTURE 3. REDUCED EXERCISE CAPACITY	MECHANICAL STRESS, PSYCHIC STIMULATION WEIGHTLESSNESS AND RELATIVE INACTIVITY	EXTENSIVE
BLOOD	POSTLANDING 1. MODERATE LOSS OF BLOOD VOLUME 2. MINIMAL LOSS OF PLASMA VOLUME 3. DECREASED RED-CELL MASS 4. INCREASED WHITE-CELL COUNT	WEIGHTLESSNESS AND RELATIVE INACTIVITY OXYGEN ATMOSPHERE AND WEIGHTLESSNESS GENERAL STRESS	MINIMAL
CENTRAL NERVOUS	INFLIGHT 1. SLEEP PROBLEMS 2. MOTION SICKNESS (APOLLO 8 & 9)	DISRUPTION OF DIURNAL RHYTHMS, NON-SIMULTANEOUS SLEEPING OF CREW, POSITIVE EXCITEMENT, THREAT OF POTENTIAL DANGER AND UNFAMILIAR ENVIRONMENT (WEIGHTLESSNESS, CRAMPED QUARTERS, RESTRAINTS, ETC.) UNRESTRAINED IVA UNDER WEIGHTLESSNESS	MINIMAL
RESPIRATORY	POSTFLIGHT SOME REDUCTION IN VITAL CAPACITY	SPACE CABIN ATMOSPHERE (PRESSURE AND COMPOSITION)	MINIMAL

that human life sustaining processes at the cellular level will be affected directly by long-term exposure to zero-g.

During the course of evolution multicellular organisms have developed specialized physiological systems that are adapted to gravity. In the human organism gravity-dependent systems include the musculoskeletal (weight bearing structure), the proprioreceptive/vestibular (body position sensing organs) and the cardiovascular (essentially a blood pumping and distribution network operating against the hydrostatic weight of the blood column). Note, however, that sensing the direction of the gravity vector through the proprioreceptive/vestibular organs is at least a partially acquired reaction which pilots, for instance, can learn to suppress with training.

Observations confirm that definite physiological changes attributable to space flight occur in these three systems and the hematopoietic (blood forming) system as well. The effects on hematopoiesis (primarily a reduction in red cell mass) appear to be caused by breathing pure oxygen rather than by weightlessness, and can be duplicated in the laboratory. Since current plans envisage a change-over from a one- to a two-gas system, hematopoietic effects are not likely to constitute a problem. Red cell mass determinations in Apollo support this position (Ref. 6). The Apollo spacecraft is launched with approximately 60% O_2 and 40% N_2 which is altered in flight toward 100% O_2 but which normally levels off around 93%. In this environment, the decrease in red-cell mass has been consistently small and medically insignificant. However, in Apollo 9 where LM activation and extravehicular activity required decompression of the CM (exposure to the space vacuum) and subsequent repressurization with 100% O_2, post-flight examination revealed a modest but significant loss of red-cell mass (Ref. 6). This finding lends further support to the hypothesis that pure oxygen atmospheres are predominately responsible for the observed loss in red-cell mass.

The musculoskeletal system responds to mechanical stimulations in several characteristic ways. Muscles build up and bones are fortified whenever the body is exposed to increased mechanical loading over prolonged periods of time.

Conversely, the muscle mass is reduced and the bone structure demineralizes during periods of low mechanical loading.

The extent of bone demineralization and the loss of protein nitrogen from muscle tissue that have been reported to date are by no means indicative of musculoskeletal damage. Moreover all losses to date have been replenished within a short time following each flight. However, there is some concern that continued losses in extended missions could significantly increase bone fragility, muscular weakness and the probability of kidney stone formation. These first two effects are of obvious importance for successful re-entry and re-acclimatization to the 1g environment upon return. Table 2 summarizes the major effects of weightlessness on the musculoskeletal system.

Weightlessness also has other important effects. Perception of the position and movement of the different parts of the body with respect to each other as well as the maintenance of equilibrium depends upon appropriate sensations transmitted to the brain from the joints, muscles, tendons, eyes and the vestibular apparatus. The most important organs of equilibrium are the vestibular and visual systems.

Peculiar sensations attributable to vestibular responses in the zero-g environment have been reported by both U.S. and U.S.S.R. crews. These include early short-lived postural illusions in the absence of visual cues, longer lasting motion sickness symptoms during unrestrained IVA, and temporarily increased sensitivity to the mechanical forces of re-entry and landing. It has been suggested that prolonged understimulation of the vestibular system in the weightless environment may lead to its structural or functional degradation. However, normal head movements and frequent whole-body translations during unrestrained IVA appear to provide enough inertial stimulation to the vestibular system to prevent the development of significant disorders. Results of space flight experiments on bullfrogs indicate that after an initial period of several days of increased neural discharge rate, vestibular responses return to their normal prelaunch levels (Ref. 7). The initial increase in neural discharge rate corresponds to an increase in vestibular sensitivity indicating an attempt to maintain the normal gravity references. Similarly, the return of the neural discharge rate to prelaunch normal levels indicates that both the vestibular organs and the spatial orientation

TABLE 2

EFFECTS OF WEIGHTLESSNESS ON THE MUSCULOSKELETAL SYSTEM

PRIMARY EFFECTS	SECONDARY EFFECTS	FAILURE MODES
I. ANTIGRAVITY MUSCLES ATROPHY FROM DISUSE.	1. MUSCLE TISSUE ACTIVITY AND VASCULARITY DECREASES, LOWERING CARDIAC OUTPUT REQUIREMENTS. 2. AVERAGE METABOLIC RATE DECREASES, LOWERING OXYGEN CONSUMPTION REQUIREMENTS AND RED CELL CONCENTRATIONS.	a. MUSCLES WEAKEN AND PHYSICAL WORK CAPACITY DECREASES.
II. BONES DEMINERALIZE.	1. HIGH CALCIUM EXCRETION RATES INCREASE THE PROBABILITY OF KIDNEY STONE FORMATION. 2. IN CASE OF FRACTURE, BONE HEALING TIME IS PROLONGED.	a. BONES BECOME MORE FRAGILE. RE-ENTRY AND POST-LANDING STRESSORS ARE LESS TOLERABLE.

mechanisms of the central nervous system adjust to weightlessness. Table 3 summarizes the major effects of weightlessness on the vestibular system.

The cardiovascular system also shows effects of weightlessness. In the terrestrial environment the hydrostatic pressure of the blood column changes when an individual undergoes a change in posture (e.g., from the supine to the erect position). Normally, cardiovascular reflexes are triggered to compensate for this gravity effect on Earth. In weightless flight there is no hydrostatic pressure difference associated with changes in posture. This suggests, and flight results confirm, that the cardiovascular reflexes become deconditioned in zero-g conditions. Changes in vascular distensibility and decreases of vasoconstrictive hormones have also been suggested as additional factors that may further aggravate this cardiovascular deconditioning during prolonged missions.

Transient shifts in body fluid distribution have also been observed, beginning with the Mercury flights. They are similarly attributable to the loss of hydrostatic pressure of the blood column in weightlessness. This fluid shift reduces the normal tendency for blood-pooling in the lower extremities and results in more blood entering thoracic vascular spaces, stretching vessel walls and initiating, through neuroendocrine pathways, a reduction of total water content in the body. Table 4 summarizes the major effects of weightlessness on the cardiovascular system.

At present it is still not certain whether or not the observed physiological changes will be self-limiting as mission duration increases. It is also possible that physiological normalcy in space differs from that on Earth to the extent that significant deviations from acceptable terrestrial limits will be required for successful acclimatization to prolonged space flight. If the latter proves to be true, then man's ability to tolerate re-entry and post-landing stresses could be impaired without producing functional degradation during flight. For example, body water content has been consistently observed to decrease during flight, and we can assume that this is a normal adaptation to space flight. In Figure 1 the normal and altered distributions of body water content are plotted. Like other physiological variables there is a spread of values for different people as well as a fluctuation for a given individual in time. The figure shows that, even though there is a significant overlap in

TABLE 3

EFFECTS OF WEIGHTLESSNESS ON THE VESTIBULAR SYSTEM

PRIMARY EFFECTS	SECONDARY EFFECTS	FAILURE MODES
I. THE OTOLITHS ARE UNDER-STIMULATED BECAUSE OF REDUCED MECHANICAL LOADING	1. INCREASED VESTIBULAR SENSITIVITY TO LINEAR ACCELERATIONS CAN OCCUR FOLLOWING PROLONGED EXPOSURE TO ZERO-G.	a. OTOLITHS MAY ATROPHY FROM DISUSE AND PERFORM ABNORMALLY UPON RETURN TO THE 1-G ENVIRONMENT.
II. THE INFORMATION TRANSMITTED FROM THE OTOLITHS TO THE CNS DOES NOT CONFORM TO EXISTING PSYCHOSENSORY MODELS.	1. MOTION SICKNESS SYMPTOMS CAN BE EXPERIENCED EARLY IN THE FLIGHT. 2. POSTURAL ILLUSIONS ARE POSSIBLE IN THE ABSENCE OF VISUAL AND PROPRIOCEPTIVE CUES. 3. PERCEPTION OF PERSONAL ORIENTATION IS MAINTAINED THROUGH VISION, MUSCLE AND TENDON PROPRIOCEPTORS AND SKIN TOUCH RECEPTORS.	a. CNS POSTURAL AND MOTION CONTROLS MAY DEGRADE IN WHICH CASE CONTROL OF THESE WILL REQUIRE RE-LEARNING UPON RETURN.

TABLE 4

EFFECTS OF WEIGHTLESSNESS ON THE CARDIOVASCULAR SYSTEM

PRIMARY EFFECTS	SECONDARY EFFECTS	FAILURE MODES
I. ABSENCE OF HYDROSTATIC PRESSURE ON BLOOD ELIMINATES BACK FLOW TENDENCIES AND REDUCES POOLING IN LOWER EXTREMITIES.	1. ONE-WAY VASCULAR VALVES CAN UNDERGO DISUSE ATROPHY. 2. MUSCULAR TONUS REDUCES INTRINSICALLY AND EXTRINSICALLY. THE LATTER AS A RESULT OF DECREASED NEURAL AND HUMORAL STIMULATIONS. 3. BODY FLUIDS SHIFT THROUGH ACTIVATION OF THE GAUER-HENRY REFLEX.	a. COMPLIANCE OF VASCULAR WALLS INCREASES AND VASOACTIVE HORMONE RESERVES DECREASE, LEADING TO DECREASED ORTHOSTATIC TOLERANCE IN THE POST-FLIGHT PHASE. b. PLASMA LOSSES CONTRIBUTE TO DEHYDRATION AND POST-FLIGHT ORTHOSTASIS.

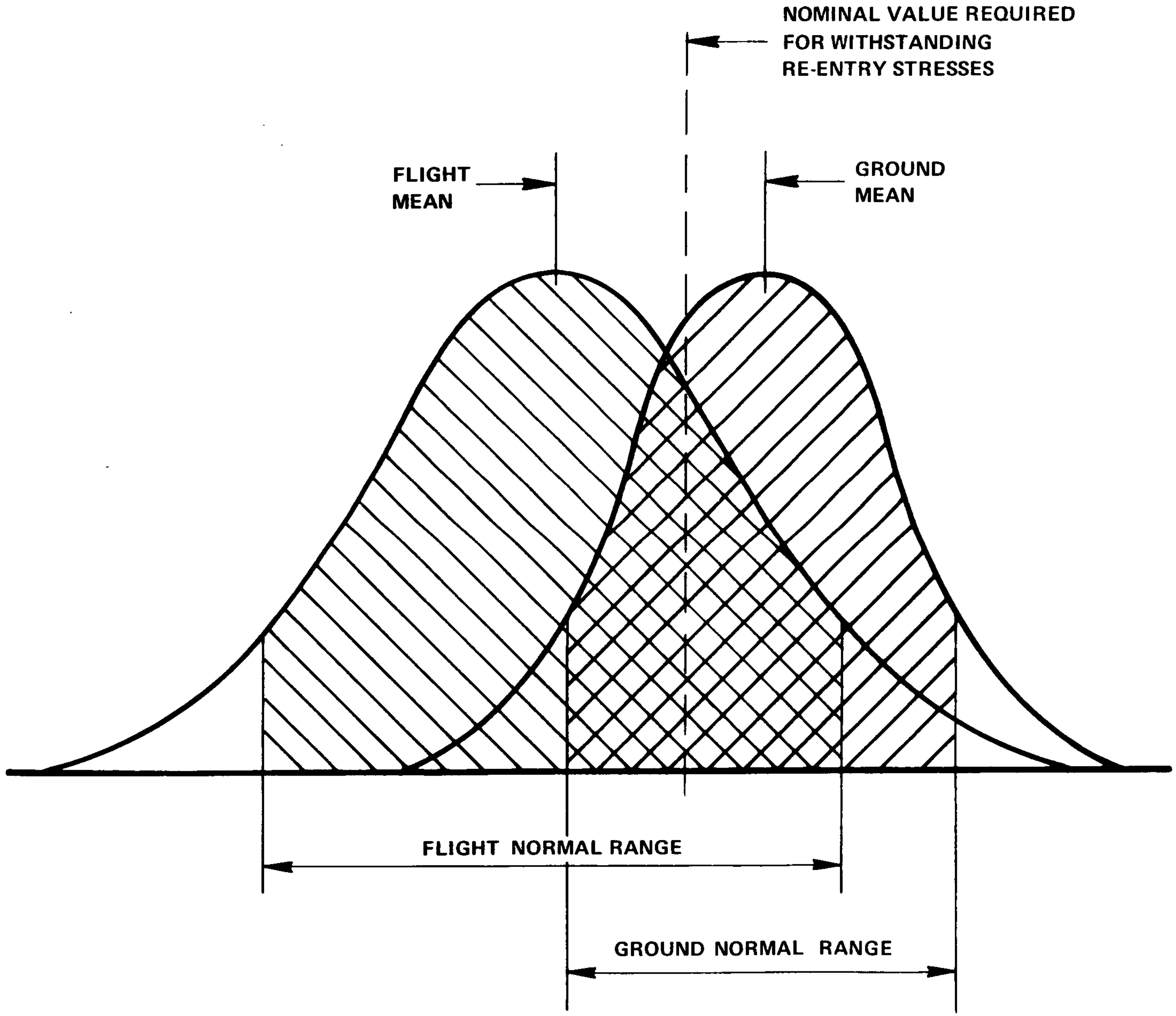

FIGURE 1 - CHANGES IN THE FREQUENCY DISTRIBUTION OF A TYPICAL PHYSIOLOGICAL PARAMETER AS A RESULT OF SPACE FLIGHT

the two situations, the fraction of people having enough body water content to withstand re-entry stress is much less in the flight population than the ground population. This situation is expected to worsen as the region of overlap decreases.

To assay the physiological cost of maintaining a given level of inflight performance, two groups of stress hormones have been measured post-flight on urine samples collected in- and post-flight: catecholamines and 17-hydroxycorticosteroids. The catecholamines provide a measure of short-term or emergency response. Assays of catecholamines from inflight urine samples are uncertain mainly because the changes observed appear to be well within the error of the methodology. Levels of 17-hydroxycorticosteroids were found to be depressed by space flight. An elevation immediately post-flight was observed in both hormonal groups, but this could be related to the stresses of re-entry and recovery.

On the basis of these findings, one could suggest that weightlessness is a lower stress situation than the normal gravity environment. If this is true, then one may also suggest the possibility of progressive reduction in endocrine stress reserves during prolonged space flight and argue for the need of appropriate countermeasures (e.g., vigorous physical exercise). However, these data are only preliminary and further information must be obtained before valid interpretations and final judgments can be made.

Apart from weightlessness, another characteristic of the space environment having physiological significance is the inherent alteration or absence of daily periodicities due to geophysical cycles. Such periodicities are among the most important factors synchronizing the physiology of all living organisms. Whether the primary timing oscillators for such biorhythms are in the organism itself or in the organism's external environment is presently uncertain. Whichever the case might be, the environment exerts a dominant role in either entraining or inducing physiological rhythms in synchrony with the 24-hour daily cycle. Preliminary observations indicate that altered rhythms in heart rate, in the duration of the electromechanical systole and in the entire cardiac cycle persist for at least several days following exposure to space flight conditions (Ref. 8). It is not clear from the available data, however, whether or not these new rhythms are 24-hour synchronized. If their periods deviate from 24 hours, then it is very probable that the normal phase relationships existing among mutually supportive processes are also disrupted. In such a case, there is a possibility of eventual physiological maladjustment.

2. THE NEED FOR ARTIFICIAL GRAVITY

The creation of an artificial gravity environment in manned space flight systems has often been proposed as a means of preventing physiological deconditioning, improving habitability and preserving astronaut work-effectiveness. In Appendix C this issue is discussed and it is concluded that there is currently no physiological basis for requiring that future long-duration spacecraft have artificial gravity.

3. INVESTIGATIVE STRATEGIES

Factors that are believed to be biomedically and behaviorally significant for man in space include: weightlessness, radiation, removal from normal geophysical periodicities, decompression, artificial atmosphere, atmospheric contaminants, mechanical forces, confinement and isolation from family and friends.

The effects of almost all these factors can be simulated and evaluated individually and in various combinations in ground-based studies. However, long-term weightlessness and the composite flight situation cannot be duplicated in the laboratory. Consequently, both ground-based and in-flight efforts are required to establish the rates of change, time course and severity of these effects, and also to uncover any additional effects beyond the capabilities of ground-based studies.

3.1 The Need for Change of Monitoring Rationale

The key variable in space-rating man is duration of flight. Evaluation of the ability of crews to withstand extensions in flight duration has been, and still is, based on two distinct operational approaches: real-time safety monitoring and inflight investigative measurements.

Monitoring of physiological status during flight is necessary to provide information for real-time decision making. Judgments concerning the continuation of an ongoing mission are made on a day-to-day basis with the understanding that all earth-orbital flights can be terminated at will. In past flights as well as in the Skylab program, routine monitoring includes the telemetering of heart rate, electrocardiogram, impedance pneumograph and body temperature, although not always concurrently for all crewmembers. Astronaut self-assessments and reporting of subjective and objective information are also available.

Inflight investigative measurements have so far been designed for post-flight analysis. They have helped assure that planned increases of flight duration on subsequent missions will not be likely to endanger the well-being of the crew. In the past, it has been assumed that successive doublings of the flight duration would not exceed the crew's physiological limits. The decisions to double were based on: (a) the physiological state of each astronaut as measured before and after the flight and (b) the post-flight analysis of experimental data collected inflight. This overall approach has been successful for short and intermediate missions, up to 14-days duration. However, the risk increases with increasing exposure increment, if the inflight safety indices used are not sufficiently encompassing, sensitive or predictive* of detailed physiological functioning. It is thus possible that long-term flights might reveal that:

a. Inflight well-being deteriorates appreciably before either the astronauts or ground control become aware of the problem. This could happen either because real changes are unconscious or because compensatory mechanisms mask the degradation processes. In either case the crew will be exposed to the additional re-entry and recovery stresses before they can receive external medical assistance.

b. Inflight well-being is maintained, but adaptive processes advance to the point where the ability of the crew to tolerate stresses of re-entry and post-landing periods is impaired without the vital signs showing abnormal response during routine safety monitoring.

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*Reliable prediction of physiological effects requires knowledge of their underlying biological processes.

Based on the above considerations it appears advisable to integrate safety monitoring and medical experimentation efforts. Data from inflight investigative measurements should be made available for analysis in near real-time to supplement ground-based medical monitoring information. In addition to such diagnostic support, biomedical experiments should be designed to satisfy preventive and therapeutic needs as much as possible.

3.2 Pre- and Post-Flight Measurements

Pre- and post-flight measurements are needed for several purposes: to detect and rectify any medical problems imminent or developing in the immediate preflight period: to identify and assess any residual changes in the physiological status of the crew as a result of space flight, and to establish baselines for interpreting inflight changes (both in rate and degree). The following basic sets of measurements should be conducted:

a. Comprehensive physical examinations.

(First-order discrimination techniques for health and disease states). This includes height, weight, audiometry, visual performance, EKG, chest x-ray, neurology and vital signs.

b. Blood and urine biochemistries.

(Higher-order discrimination techniques for health and disease states). Collect data on circulating blood elements, humoral and cellular factors associated with immunity, and selected blood and urine chemical constituents.

c. Assessment of microbiological flora.

Collect data on the effects of the space flight environment on the indigenous microbiota of man. Microorganism profiles of crew members, clothing and spacecraft locations should be catalogued.

d. Response to whole-body exercise.

Assess cardiopulmonary function.

e. Tilt-table and/or lower body negative pressure tests.

   Assess cardiovascular reflexes.

f. Bone densitometry.

   Determine extent of bone demineralization.

g. Toxicological assessment.

   Identify residual gaseous and solid contaminants in the spacecraft suit loop and cabin environments.

h. Pharmacological assessment.

   Identify responses to medications which might be taken during flight.

3.3 In-flight Measurements

In-flight measurements serve two major purposes: to assess the physiological status of each crew in the operational environments at regular intervals, and to expand the body of scientific knowledge concerning the effects of space flight on man. The first assures the safety of the men being monitored and the second also helps assure the safety of subsequent crews.

The following measurements, classified into major investigative areas constitute a minimum acceptable flight program. Data from these measurements should be analyzed in real or near-real time:

a. Environmental Parameters. Parameters of the physical environment of the astronaut should be measured periodically so that meaningful correlations and inferences can be made. Parameters of interest include: atmospheric composition and pressure, atmospheric contaminants, ambient temperature, relative humidity, astronaut and spacecraft microbiological flora and radiation levels.

b. General Physical Well-Being. Real-time operational monitoring of the basic physiological indices employed in the past should continue (i.e., astronaut self-assessment, electrocardiography, respiration rate and depth, blood pressure, and body temperature).

c. Nutrition and Musculoskeletal Conditions. Input and output of fluids plus the amounts and varieties of food consumed should be recorded. Measurements of electrolytes in urine should be conducted and correlated with known electroyte intake. Biochemical constituents in feces should be determined. Body weight should be measured on a regular basis. A photon absorption device should be developed and used for conducting bone mineral measurements during prolonged man-rating flights. A whole-body exerciser (preferably a device which exerts compressive forces on the body) should be developed and used for preventing or correcting possible muscular weakness and excessive skeletal demineralization during long-term missions.

d. Cardiovascular Status. A lower body negative pressure device or an equivalent system should be used periodically to detect changes in cardiovascular reflexes by measuring heart rate, blood pressure and leg volume responses to provocative tests. Such a device effectively produces blood pooling in the lower extremities in a manner similar to that of a gravity stimulus. The same device and/or the whole-body exerciser could be used for minimizing or correcting possible cardiovascular degradation.

e. Energy Metabolism. A bicycle ergometer should be used to determine changes in energy expenditure during calibrated workloads as a function of time. This device can also be used to determine the response of the cardiovascular system to varying workloads. Energy expenditures should also be measured during actual intravehicular and extravehicular tasks.

f. Biorhythms. Man's normal periodicities in such functions as thermoregulation, circulation, respiration and hormonal secretion should be measured for possible time-related changes. Parameters of interest should include, but not necessarily be limited to, body temperature, heart rate, respiration rate and rest/activity cycles. Sampling frequency should be high enough to permit detection of shifts in diurnal patterns.

g. Endocrinology. The basic pattern of general stress response to almost every type of stressor, such as injury, infection, poisoning, emotional reactions, pain, shifts in homeostatic parameters, and external physical changes (cold, heat, etc.) provides measures of great significance. Adrenocortical hormones are secreted non-specifically in response to stress in a manner reflecting the intensity of interaction between organism and environment. Consequently, the level of corticoid circulation in the blood and excretion in the urine is an important index revealing general crew stress status. Determinations of 17-hydroxycorticosteroid concentrations in urine should be made feasible for flight application and conducted on a regular basis. If the artificial space flight environments are stressful these measurements will reflect it. Alternatively, if situational changes occur, monitoring of these hormones can be used to safeguard the crew against exposure to nonspecific long-term stress.

Data resulting from the above measurements should be statistically analyzed so that similarities and differences between individual astronaut responses can be identified and predictions concerning future changes in physiological state can be developed. Data derived from each crew member on a given day can be represented as points in a multidimensional space. Computed distances between points are then measures of clinical dissimilarity (Ref. 10). The time-profile of each crew member's data in this space indicates the clinical course of his physiological state. Using such computerized techniques it is not only possible to handle and compress large amounts of data, but also to identify the pathways joining successive physiological states, and estimate the likelihood of a change from one particular state to another. Appropriate statistical/mathematical medical programs are available in the Manned Space Flight Data Processing System, within the Statistical Analysis Subsystem (Ref. 11).

3.4 Guidelines for Physiological Investigations

The following set of guidelines should be used to evaluate each physiological investigation suggested for flight:

a. Evaluate each relevant physiological system or function. Identify its essential anatomical or operational characteristics. (i.e., what is its job and how does it work?)

b. Review its evolutionary development in order to identify what environmental problems were encountered and how they were solved (i.e., why is the system put together the way it is?)

c. Identify the primary failure modes* fo. each system or function.

d. Establish the level of criticality** for each primary failure mode.

e. Identify the impact of each primary failure mode on other systems or functions.

f. Select those critical failure modes which can be induced by the environmental conditions of space-flight.

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*Failure modes are those physiological changes that lead to conditions outside the normal range of accepted well-being.

**The level of criticality of a failure mode is the extent to which it jeopardizes human performance. The degree of jeopardy can range through a series of levels from discomfort to incapacitation or death. More specifically, one may classify failure modes into three levels or categories of criticality: operational level (situational awareness), physiological level (pain, discomfort or functional impairment), and biological level (functional incapacitation or death).

g. Identify and conduct the ground-based research necessary to explain the mechanisms of the failure modes selected.

h. Using this ground-based experience develop techniques to predict or prevent primary failure modes from occurring, and to stop their spread to other systems or functions.

i. Monitor the systems or functions in-flight to safeguard against the occurrence of failures. Apply appropriate counter-measures if failure is predicted, imminent, or manifested.

4. RESEARCH AND DEVELOPMENT

The requirements for research and development are identified below (see Vol. 1 of this document (Ref. 12) and Ref. 13, 14). The resulting data base must be of sufficient depth to permit statistically confident decisions for future manned space flight operations and to optimize the design of advanced space systems.

4.1 In-flight Investigational Aims

Neurophysiology

1. Determine the effects of space flight on central nervous system function.

2. Determine the effects of the space flight environment on sleep patterns.

3. Determine the change in susceptibility to motion sickness as a function of:

   a. Time aloft

   b. Freedom of movement within the spacecraft

   c. Rotation of the spacecraft

   d. Rotational perturbations of vehicle

4. Determine the effects of sustained weightlessness on the functional response of the vestibular organs.

5. Determine the effects of sustained loss of gravitational cues on sensory and spatial orientation capabilities, proprioception, and kinesthesis.

Pulmonary Function and Energy Metabolism

1. Determine the effects of sustained weightlessness on the mechanics of breathing and the interaction of gravitational forces with the respiratory muscles and the elastic forces of the chest and lungs.

2. Determine energy costs (metabolic gas exchange) at rest and during activity within the space cabin in suited and unsuited modes during normal flight, during EVA, and during operational activities on non-terrestrial bodies.

3. Determine the degree and duration of arterial hypoxia due to pulmonary ventilation/perfusion inequality during spacecraft launch and re-entry.

4. Determine the occurrence of any alterations in alveolar gas transfer and in the control of breathing under prolonged combined effects of weightlessness and a low-pressure mixed gas and/or pure oxygen environment. Delineate mechanisms involved if changes are found.

5. Determine if either a compensatory acidosis or alkalosis is occurring.

Cardiovascular Function

1. Determine the accommodations of the cardiovascular system to weightlessness, the mechanics which mediate these accommodative changes, and identify means by which the system can be aided to withstand the stresses of re-entry and post-flight return to earth.

2. Determine how adequately cardiac output is maintained in prolonged space flight.

3. Determine the extent to which space flight affects normal arterial pressure controls.

4. Determine how venous compliance, central venous pressure, and their adjusting mechanisms, are influenced by prolonged space flight.

5. Determine how cardiac function is affected by long duration space flight.

6. Determine the factors of space flight which cause changes in circulatory blood volume, blood distribution and the blood plasma/cells ratio. Determine the point and conditions under which a new equilibrium is established.

7. Determine the time-course of changes in overall circulatory function as determined by provocative testing (tilt-table, LBNP).

Nutrition and Musculoskeletal Function

1. Determine actual caloric profiles and the variables affecting caloric utilization under different workloads and varying space suit configurations in long duration space flight.

2. Determine the space flight factors or stress conditions which might change caloric, water, electrolyte, or mineral requirements.

3. Establish predictive values for differences between energy costs of activity in space and in the 1g environment.

4. Determine the extent to which glucose metabolism may be altered by space flight conditions

5. Determine whether variations in body mass during space flight are within expected and acceptable limits, assuming adequate food and water intake and work schedules comparable to those observed in Earth environment.

6. Determine the time-course and degree of skeletal and muscular changes due to weightless flight. Assess the relative influences of weightlessness, relative inactivity, and the gaseous atmospheric environment.

7. Determine the best preventive and/or remedial measures to counteract bone and muscle deterioration coincident with space flight (consider the applicability of special diets).

8. Determine the effects of long duration weightless flight on water and electrolyte balance.

Endocrinology

1. Determine the extent to which weightlessness *per se* will bring about losses of fluid in view of the known changes in body water distribution and balance secondary to changes in body position. Assess how the anti-diuretic hormone is involved in these changes during weightlessness.

2. Determine the extent to which changes in the metabolic cost of activity in space will be reflected by changes in thyroid hormone production, and the extent to which a causal relationship can be established.

3. Determine the extent to which the predicted losses of minerals in long-duration space flight associated with increased bone resorption are mediated by elevated parathyroid hormone secretion.

4. Determine the extent and time-course of changes in adrenal cortical activity during prolonged space flight as both a reflection and mediating factor of stress response.

Hematology and Immunology

1. Determine the environmental factors responsible for the loss of red cell mass noted during Gemini. Determine the relative roles of:

   a. The 100% oxygen environment

   b. Nitrogen in small amounts

   c. Weightlessness

   d. Duration of exposure

   e. Diminished red cell production vs. increased destruction

f. Ambient total pressure

g. Vibration

h. Ambient temperature

i. Dietary factors

2. Determine the influence of long-duration space flight on the coagulation process and platelet function.

   Assess the environmental factors responsible for such changes.

3. Determine and evaluate any alterations in inflammatory response which may occur as a result of long-duration space flight.

4. Determine the extent to which space flight may influence cell mitosis and/or chromosomal composition. Determine which environmental factors are responsible, and what preventive action can be taken, if such changes occur in flight.

Microbiology

1. Determine the changes which may be expected in the microbial flora of flight crews during space flight.

2. Determine the influence of space flight conditions on the relative dominance of pathogenic microoganisms.

3. Determine whether, and to what extent, genetic alteration in microbiological organisms can be expected to occur as a result of the space flight environment. Ascertain whether a pattern of such changes can be anticipated.

4.2 Ground-Based Definition Studies, Development Activities and Investigational Aims

Bioinstrumentation

1. Develop non-invasive, sensitive, and compact personal biotelemetry systems that will provide

physiological assessments both to the crew and to remote monitors without the physical interference of hard-line umbilicals.

2. Develop bioinstrumentation which will permit inflight determination of: cardiac output, arterial pressure, central and peripheral venous pressure, electro-mechanical cardiac responses, regional blood volume distribution, bone density, urine constituents, acid-base balance, astronaut and environmental micro-flora, atmospheric contaminants.

3. Define water, food intake, sweat, urine and feces monitoring requirements, establish measuring techniques and develop analytic modeling and data management systems.

4. Develop non-invasive indicants and biochemical monitoring methods to substitute for direct measures of blood chemistry (examine informational content in sweat and saliva).

Environmental Physiology

1. Define the medical bases for evaluating the risks in progressively longer manned flights.

2. Define acceptable functional limits to flight-induced physiological changes.

3. Investigate the necessity for, and the implications of, artificial gravity. Define potential countermeasures (other than artificial gravity) to probable decrements attributable to weightlessness.

4. Identify a minimal set of reliable physiological indices for detecting and predicting physiological and performance degradations, before those conditions become critical.

5. Identify needed precursor and supportive in-flight animal studies.

6. Study the effects of weightlessness within ground-based analogues. Establish the qualitative and quantitative relationships between ground-laboratory results and inflight events. Define

what information and techniques can be developed on the ground and what must be done in-flight.

7. Define nominal comfort limits and contingency tolerance limits to noise, vibration, acceleration and impact during launch and re-entry for crews containing passenger astronauts.

8. Study the etiology, symptomatology and prevention of vestibular sickness. Study additionally the responses of labyrinthine-defective subjects.

9. Continue simulation studies (e.g., rotating rooms) to establish advanced design criteria for spinning spacecraft.

10. Determine the time profile and degree of skeletal changes induced by various forms of inactivity under atmospheric compositions and pressures similar to those employed in flight.

11. Study the effect of candidate space cabin atmospheres on acid-balance.

12. Define nominal nutritional requirements for extended missions (e.g., minimum protein needs, vitamins, minerals, etc.).

13. Define desirable diet composition and mixes (e.g., proteins, carbohydrates, fats, etc. and freeze-dried, frozen, natural and synthetic food ratios).

14. Develop foods with improved palatability, menu variety, desirable flavors, and simple reconstitution and preparation techniques.

15. Define nutritional deficiency detection techniques and countermeasures.

16. Define microbiological standards and control procedures for the water and the waste management systems.

17. Study the effects of acceleration, vibration and hyperoxia on erythrokinetics and hemolysis.

18. Study the effects of acceleration, vibration, temperature and hyperoxia on coagulation factors and on lymphocyte chromosome numbers.

19. Investigate the epidemiological implications of biologically isolated populations and environments.

20. Study changes of microflora population with time under simulated space flight conditions and during animal experiments in space.

21. Set radiation exposure limits and develop protection techniques.

<u>Life Support</u>

1. Define acceptable atmospheric parameters (total pressure, composition, temperature and humidity) for alternate advanced programs.

2. Clarify the potential incidence of dysbarism following either planned operational or unanticipated emergency decompressions. Evaluate candidate space cabin atmospheres, alternate environment choices, and present space suit concepts.

3. Define and conduct studies to specify exposure limits to toxic atmospheric contaminants.

<u>Hazard Protection</u>

1. Develop detection techniques and a self-contained emergency breathing apparatus for use inside the space cabin as protection against buildup of atmospheric contaminants.

2. Develop inflight fire-fighting techniques and equipment.

3. Develop a vomit removal apparatus compatible with operations under suited conditions.

4. Identify and develop detection-warning systems, safety provisions and emergency procedures to protect crew from critical systems failures (e.g., ECS, EPS, etc.), and space environment hazards (e.g., capsule puncture, solar flares, etc.).

Clinical Medical Support

1. Define the situations where administration of drugs is most desirable. Define pharmaceutical preparations, packaging and administration techniques.

2. Define monitoring methodologies to delineate clinical symptoms which might be endemic to space.

3. Examine the applicability, advantages, and limitations of "telemedicine" (practice of medicine at a distance) for planetary missions.

4. Define the extent and nature of inflight diagnostic and treatment capabilities that must be available in long-term missions.

5. Develop infusion, transfusion and surgical techniques for inflight use.

6. Define prophylactic clinical treatment that may be applied before crew commitment to deep space, long-term missions.

7. Define the skill requirements for on-board medical personnel during prolonged missions.

Ground Support Facilities

1. Define ground facility requirements for the real-time biomedical support of long-term earth orbital, lunar and planetary missions.

2. Define biomedical ground facility requirements for launch support, recovery operations, and flight crew quarantine for future multi-man, long-term missions.

INFLIGHT BEHAVIOR AND PERFORMANCE

1. REVIEW OF FLIGHT EFFECTS

The scope of human activities in space flight has grown tremendously. Man's initial role was that of a passenger and backup pilot, briefly confined in the small, suborbital Mercury vehicle. He now aims for almost the whole range of scientific, technical and self-maintenance activities which individuals and small groups can ordinarily perform on earth.

Man's short-term survival and functional potential have been demonstrated. Since the initial exploratory phases of space flight scores of men (and a woman) have shown that, given appropriate training and supportive technology, human beings can adapt to a variety of extraterrestrial conditions and effectively perform a wide range of complex intellectual and physical tasks. We now need to gain a greater understanding of man's interrelated behavioral and physiological processes so that the fullest possible range of performance can be achieved for long-duration missions.

Inflight investigations have ranged from quantitative comparisons of overall task times and visual capabilities to qualitative assessments of psychomotor effects on task performance under IVA and EVA (Refs. 6 and 29). Sensory and information-processing capabilities have typically shown no significant decrements in weightlessness. However, physiological effects of zero-g adaptation have included temporary performance incapacitations due to nausea, and EVA tasks have induced rapid breathing and sweating. In addition, almost all the crewmembers in Apollo 7 through 11 demonstrated significant post-flight decrements in physical work capacity, compared with pre-flight baselines.

Our present information on the major effects of space systems factors on basic performance characteristics is summarized in Table 5 (adapted from Ref. 2). The use of men in space must be justified by how well we apply their unique combinations of abilities, so as to contribute to a range of scientific and technical activities that cannot be performed as effectively, or as economically, without them. The information base to support these capabilities must be developed (Ref. 15).

TABLE 5
MAJOR EFFECTS OF SPACE ENVIRONMENT FACTORS
ON COMPONENTS OF PERFORMANCE

SPACE ENVIRONMENT FACTORS / PERFORMANCE COMPONENTS			SENSORY MODES					OUTPUT CHARACTERISTICS							
								FUNCTION						QUALITY	
			VISION	AUDITION	SOMESTHESIS	SMELL	TASTE	ORIENTATION	POSITION KEEPING	TRANSLATION	PSYCHOMOTOR RESPONSE	VERBAL COMMUNICATION	WORK CAPACITY	ACCURACY	RESPONSE TIME
INHERENT	INTRAVEHICULAR	WEIGHTLESSNESS						P	D	D			D		P
		RELATIVE PHYSICAL RESTRICTION												P	P
		ALTERED PERIODICITIES												?	?
		LACK OF MAGNETIC FIELD	?											?	?
		ENRICHED OXYGEN ATMOSPHERE	P												
		DILUENT GAS (OTHER THAN N_2)										P			
		LACK OF DILUENT GAS											P		
		ARTIFICIAL GRAVITY						P		P	P				
	EXTRAVEHICULAR	SUBGRAVITY STATE								P			P		
		LACK OF LIGHT DISPERSION MEDIUM												P	P
		PRESENCE OF SPACE SUIT	P								P		D		P
		NEED FOR TRANSIENT DECOMPRESSION	P		P										P
EXTRANEOUS	MECHANICAL	NOISE	X	X								X	P	X	X
		VIBRATION	X		X						X	X	X	X	X
		LINEAR ACCELERATION	X		X			X	X	X	X	X	X	X	X
		ROTATION						X	X	X	X	X	X	X	X
	AMBIENT	OXYGEN STARVATION	X	X	X	X	X	X	X	X	X	X	X	X	X
		CONTAMINANTS ACCUMULATION	P	P	P	?	?	P			X		X	X	X
		LOW OR HIGH TEMPERATURE	P	P	P	P	P	P	P	P	D	D	X	X	X
		LOW BAROMETRIC PRESSURE						P			P	P	P	P	P
	PHYSIOLOGICAL	INADEQUATE O-G ACOMMODATION			X			X	X	X	X		D	X	X
		EXPOSURE TO RADIATION						X			X		X	X	X
		DISEASE	?	?		X	X	X	P	P	X		X	X	X
		INJURY	P	P	P	P	P	P	P	P	P	P	P	P	P
	HUMAN ENGINEERING	INEFFICIENT WORK-REST CYCLES									X	P	X	X	X
		INADEQUATE TRAINING									X		X	X	X
		LOW VOLUME PER MAN RATIO						P		X	X		X	X	X
		INEFFICIENT MAN/MACHINE INTERFACE									X	X	X	X	X
		SENSORY OVERLOAD OR UNDERLOAD	X	X	X	P	P				X	X	P	X	X
	MOTIVATIONAL & EMOTIONAL	LOSS OF ACCUSTOMED PATTERNS									X	D	P	X	X
		LOW INTEREST IN WORK									X	D	P	X	X
		HIGH COST (e.g., EXCESSIVE DISCOMFORT)									X	X	D	X	X
		LOW REWARD EXPECTATION									X	D	P	X	X
	SOCIAL	LIMITED SOCIAL ROLES									X	X	P	X	X
		INAPPROPRIATE CREW STRUCTURE									X	X	P	X	X
		LACK OF CENTRAL AUTHORITY									X	X	P	X	X
		LACK OF PRIVACY									X	X	P	X	X
		LIMITED INTERPERSONAL INTERACTION									X	X	P	X	X

NOTES:

P=POSSIBLE INTERFERENCE OR DEGRADATION; D=DEFINITE INTERFERENCE OR DEGRADATION
X= INDICATES EFFECTS WHOSE SEVERITY DEPENDS ON THE AMPLITUDE OF THE IMPOSED STRESS
? = INDICATES UNCERTAIN EFFECTS
WHERE NO ENTRY IS INDICATED, THE EFFECT IS CONSIDERED TO BE RELATIVELY MINOR OR IRRELEVANT

1.1 Future Needs for Behavior and Performance Information

Human beings, more than any other major parts of space systems, have many functional characteristics besides those directly relevant to the performance of mission objectives. Psychological and physiological factors of two basic types must therefore be considered in the design and control of long-term missions: (1) those on which man's functional survival and effectiveness depend, and (2) those which may interfere with mission-related functions. Since these each show significant time variations, the criteria of selection, training and systems design for short flights need not deal with the same range of potential problems as those relevant to long-duration missions.

Psychological stressors can be expected to become increasingly relevant as mission durations increase (Ref. 16). These stressors include: removal from the normal stimulus variations of the physical environment, physical confinement within the space vehicle, prolonged separation from family and friends, isolation from most contacts with earth-based groups (especially during periods of communications blackout), disruption of accustomed personal behavioral patterns, possible monotony and lack of privacy, physical danger (possible injury due to hardware malfunction or natural hazard), and inevitability (no option to withdraw from the situation after committed). Unresolved psychological stressors among crew members may lead to progressive loss of motivation, interpersonal friction, decrease in morale, breakdown of team cohesiveness and deterioration of performance (Refs.17 and 18).

Since a person's behavior and performance can be strongly influenced by his perceptions of the cost-reward tradeoffs within a situation, a crucial problem facing all maturing programs is the shift in these motivating costs and rewards that can occur over a series of repetitive missions, or during the course of a single mission. For example, the sense of personal accomplishment associated with pioneering and exploration, and the recognition from peers and society diminishes rapidly with each successive similar feat, no matter how difficult and dangerous it may be. Consider the reduction of public response to Apollo 12 after the first lunar landing.

Information on behavior and performance can be of practical engineering significance for the design of mission equipment and planning of procedures (Ref. 19). It can give answers to questions like: "How much time will the crew really be able to devote to the experiment payload?" "What are the different types of effects of equipment breakdown on crew efficiency, over and above changes in repair time?" For the spacecraft or habitat designer, the results can specify which functional areas and traffic patterns are most heavily utilized, which least, and why. Time-line planning, task allocations, and equipment design can then be refined accordingly.

Preliminary estimates of flight behavior and performance can be derived from ground studies. But the value of ground-based simulations can be greatly enhanced if we can identify the extent of their fidelity to space situations.

2. INTEGRATIVE STRATEGIES

The following sections develop some of the major relationships between behavior patterns and crew performance capabilities. They consider the potentials and tradeoffs in obtaining data from ground-based simulations and inflight observations.

The measures and methods are expected to evolve systematically as the program matures. They will serve two basic research and development needs, in addition to supplementing the safety assurance of ongoing missions: (1) to obtain the data base needed to validate the operational effects of expected man-event-environment combinations, and (2) to anticipate support needs for potential conditions within future manned flights.

2.1 Development of Behavior and Performance Information

Manned space missions are essentially dynamic combinations of men, machines, tasks and environments. The essential methodological elements for assessing the behavior and performance of these combinations are: (1) identification of appropriate systems or component descriptors, (2) measurement techniques to determine their status, and (3) interpretation of the measurements using pre-established criteria.

Data on human behavior and performance must be considered privileged information between doctor and patient. For long-term effectiveness both the methods of data acquisition and the uses of behavior and performance information must be compatible with the ethical protection of the men being studied. In-situ measurements must also strike a balance among program needs for timely information, adequate sampling for desired confidence levels, and minimizing potential interferences with other mission activities. Planning and controlling information dissemination to support scientific and mission objectives must satisfy these concurrent needs.

Data may be obtained within ground-based simulations, field studies or actual spaceflight situations. But the validity with which inflight processes can be modeled will directly depend on the fidelity of the situation in which data are obtained to the applied situations. Physical fidelity is needed for evaluation of physical effects and equipment design parameters (such as zero-g work dynamics and mobility aids); perceptual fidelity for training and task simulations (such as navigational skills or vehicle control-display interfaces); and psychosocial fidelity for behavior and performance-related stress effects (such as isolation and confinement reactions).

Despite their differences in objectives and methods, all these applications depend on the sensing of some types of data from the man-machine-task-environment combinations. Therefore, the types of data signals potentially available must be identified and evaluated. As indicated in Tables 6 and 7, many different direct and indirect signals relevant to human status may be monitored, and tradeoffs made to optimize situational compatibility. Each type of sensor has a range of optimal physical locations with respect to the human body. In some cases, these locations may result in unwanted interference with other phenomena of interest (e.g. by causing discomfort or restricting mobility). Monitoring from a distance is desirable, but not always practicable. Many measurements readily obtained within laboratory situations are not feasible within operational field situations because of these instrumentation constraints. Different measures of these phenomena would then have to be used.

2.2 Physiological Indices of Psychological Status

Physiological measures are widely used as indices of general psychological state. However, they tend to be nonspecific indicators, and may be used to supplement specific

TABLE 6

PRIMARY MAN/SIGNAL RELATIONS OF HUMAN PERFORMANCE PARAMETERS

HUMAN/SIGNAL RELATIONS	NATURE OF MONITORED SIGNALS	EXAMPLES
A. DIRECT SENSING OF HUMAN STATUS:		
MAN AS A SIGNAL GENERATOR:	SPONTANEOUS INDICANTS OF SURVIVAL AND STATUS:	[BIOMEDICAL-BEHAVIORAL NORMALCY; "VITAL SIGNS"]
	a) CONTINUOUS, OR SHORT PERIODIC SIGNALS	EEG, EKG, TEMPERATURE.
	b) LONG PERIODIC SIGNALS	BIORHYTHMS; WORK/REST CYCLES.
	c) NONPERIODIC, OR IRREGULAR SIGNALS	SPEECH; POSTURAL CHANGES.
MAN AS A SIGNAL MODULATOR:	MONITORED INPUTS AND OUTPUTS ARE OF THE SAME FORM, BUT MODIFIED BY PASSING THROUGH OR AROUND THE BODY.	VIBRATORY RESONANCES OF ORGANS AND LIMB SEGMENTS; VISIBLE LIGHT PHOTOGRAPHS; SUIT INLET/OUTLET WATER TEMPS.
MAN AS A SIGNAL TRANSDUCER:	MONITORED INPUTS AND OUTPUTS ARE IN DIFFERENT FORMS:	[BASIC TASK CAPABILITIES; "INFORMATION PROCESSING"]
	a) INNATE OPERATIONAL RESPONSES	PUPIL CONTRACTION IN LIGHT.
	b) ACQUIRED GENERAL SKILLS	VERBAL REPORT OF VISUAL SCENE.
	c) SPECIFIC LEARNED TASKS	MANUAL TRACKING OF AUDITORY CUES OR VISUAL DISPLAYS.
	d) CHANGES IN BODY FUNCTION	STRESS HORMONES IN URINE;
	OR STRUCTURE	CYTOLOGICAL SPECIMENS FOR RADIATION EFFECTS.
B. INDIRECT SENSING OF HUMAN STATUS:		
MAN AS A SIGNAL CONTROLLER:	INTEGRATED SYSTEMS AND SUBSYSTEMS STATUS, WITHOUT DIRECT MEASURES ON MAN. IF SYSTEMS ARE CONSTRAINED OR WELL MODELLED, HUMAN CORRELATES CAN BE INFERRED.	SPACECRAFT MOTIONS, FUEL CONSUMED, AND FINAL LANDING POINT COMPARED TO TARGET; TIME TO RESPOND TO SIGNALS AND CORRECT MALFUNCTIONS.

TABLE 7

PRIMARY PHYSICAL LOCATIONS FOR MAN-SENSOR INTERFACES

COMPATIBILITY OF A MAN-SENSOR INTERFACE IS DIRECTLY RELATED TO ITS FREEDOM FROM CONSTRAINING THE PHENOMENON BEING OBSERVED. APPROPRIATE SELECTION OF INPUT DEVICES PERMITS DIFFERENT TYPES OF DATA TO BE SENSED AT VARIOUS DISTANCES FROM THE HUMAN BODY.

SENSOR LOCATION	SENSOR TYPE	EXAMPLES
I. BODY CONTACT	a) INTERNAL, IMBEDDED	DEEP IMPLANT; SUBSURFACE ELECTRODE
BODY CONTACT	b) INTERNAL, NATURAL CHANNEL	CATHETER; ORAL THERMOMETER
BODY CONTACT	c) SURFACE	EEG; BIOMEDICAL HARNESS
II. BODY NON-CONTACT	d) PROXIMAL	VOICE MICROPHONE; EYE TRACKER
III. ENVIRONMENT	e) LOCAL FIELD	IVA & EVA CAMERAS; PHOTOCELLS
IV. ENVIRONMENT	f) REMOTE FIELD	RADAR; OPTICAL TELESCOPE
IV. MANNED SUBSYSTEMS	g) WORK-AIDS	TORQUE WRENCH; SPOTMETER
MANNED SUBSYSTEMS	h) INSTRUMENTS	SYSTEMS DISPLAYS; COMPUTER READOUTS

behavioral measures, but cannot independently discriminate between most alternative psychological states.

A brief summary of the most common psychophysiological indices used in ground-based studies is presented below. In operational situations it may not be feasible to measure them concurrently since the required instrumentation may limit some activities and behavior patterns.

a. Respiration: The rate and depth of respiration often change under emotional stress. Individual variability however, is high.

b. Heart rate: Based on the common experience that the heart tends to beat faster during emotional reactions, this index is probably the oldest and most widely used. It is also one of the most sensitive and simplest to measure.

c. Blood pressure: There are reasons to believe that blood pressure is responsive to changes in arousal. However, this index can be easily influenced by other factors and for this reason has been less frequently used than heart rate. Additionally, continuous monitoring is not easily achievable and its sensitivity is low.

d. Skin resistance: This index has long been employed as a measure of autonomic activity and more recently as a measure of central nervous system arousal. Galvanic skin resistance (GSR) changes accompany the perception of stimuli that require an increase in the subject's responsiveness to his environment. The level of arousal or tension at a given time has been found to relate to the absolute level of skin resistance at that time.

e. Muscle Potentials: Electromyographic (EMG) techniques permit sensitive detection and recording of the action potential of skeletal muscles.

Potentials increase with increasing level of arousal or tension even when no muscular movement is apparent.

f. Brain Potentials: Electroencephalographic (EEG) techniques permit the detection and recording of the brain's electrical activity. However, the extraordinary reactivity of the cortex, on one hand, and the high flux of incoming stimuli, on the other, make it impossible to observe any one particular effect in an entirely pure form. Since a shift from relaxed to alert behavior is also accompanied by a shift from lower to higher frequencies, this measure was used in Gemini as an index or arousal and depth of sleep (Ref. 27).

g. Catecholamines. Adrenaline and noradrenaline are the catecholamines most obviously involved in emotional responses. It has been shown (Ref.28) that there is an increased urinary excretion of adrenaline during stress associated with fear, anxiety or apprehension, with the amount of amine corresponding closely to the intensity of the stress. Increases in noradrenaline excretion are associated with such stress responses as anger and agression. Usually the urine excretion of both amines does not reflect transient changes in plasma levels. Under transient conditions urine values may not be raised above the normal limits. However, under conditions of continuous emotional stimulation, induced changes are prolonged and the levels of catecholamines will be directly related to those in the blood.

2.3 Uses of Laboratory and Field Simulations

Performance is basically the outcome of applying man's physical and mental capabilities to the accomplishments of identifiable mission objectives. As the variety and time range of these objectives progressively become more ambitious, three significant questions must be answered: (1) Are man's normal earth-based abilities to perform mental and muscular work affected by prolonged flight? (2) If so, how? (3) Can design changes minimize or prevent any undersirable effects?

Preliminary evaluations of nominal performance capabilities and behavioral patterns are usually developed within ground-based simulations. These simulations attempt to duplicate aspects of the environments and working and living conditions of projected missions using actual crews or similar populations (Ref. 30). Motivationally, however, such simulations can be considerably different from actual space flight, and these dissimilarities can produce behavioral effects which would make their direct extrapolation to space situations questionable.

A highly important difference is the low-risk low-reward environment of a laboratory simulation. Another less often emphasized distinction is the crew's lack of positive involvement in personally meaningful activities. A positive involvement, in and of itself, can alleviate the buildup of boredom and tension which often characterize situations involving extended confinement and isolation. On the other hand, involvement can also induce stresses that are not inherently related to exotic environments, per se, but are highly relevant for long-duration spaceflight. For example, in field situations, conflicts between scientific and operational demands, between pioneering enthusiasm and safety restrictions, can develop at many times across the operational period. Such tradeoffs are stressful.

Furthermore, it is more difficult for a man to dismiss frustrations or perceived inadequacies in his own performance on work in which he has career, team, and ego commitments than in simulation tasks which can be, and unfortunately often are, regarded as games.

More applicable contributions to the understanding and support of behavioral and performance aspects of space missions may be obtained from field situations that provide both high risks and high rewards as well as total immersion in exotic environments. For example, marine scientist-divers lived in, and worked from, the submerged Tektite habitat for periods up to 2 months (Ref. 21). The aquanauts could leave the habitat to conduct oceanographic observations and to study marine life in-situ. The personal costs were high, since sudden surfacing could mean considerable pain and possible death. Physical isolation from surface, family, friends and society, as well as restricted communication with the topside mission personnel, were present. Yet rewards and personal motivation were also quite high. Unrestricted visual and physical access to the underwater world were possible through the view ports in the habitat and the open hatchway to the sea. The crew's recognition of the opportunity to perform personally interesting research in such an environment was apparent and so were the prestige and publicity deriving from the accomplishment.

Thus, although the physical environments and activities in such field simulations may differ radically from those in spaceflight, behavioral stresses and small group relations may be more closely simulated in them than in studies within the mock-ups and dynamic simulators used for equipment design and training. Such equipment and task simulators are invaluable for preliminary planning and training, but offer only superficial resemblance to long-duration living and working stresses. We cannot faithfully duplicate all the complex physical and psychosocial factors involved and are not yet able to calibrate their similarity with sufficient sensitivity. We must therefore develop methods for deriving sensitive diagnostic and predictive information within actual inflight operational situations.

2.4 Inflight Behavioral Measures and Methods

Observational methods vary in sensitivity and potential interference with individual and group behavior patterns. Self-reporting of crew activities may be considered intrusive depending on the subject's evaluation of the information involved and when it is required. Similarly, such data may be subject to unconscious biases that are difficult to detect, or to errors in recall if the reports are made long after the conditions are over. The main advantage of self-reporting is technological simplicity - it requires little or no special equipment. Self-reports are therefore regularly obtained via written logs and post-flight debriefings.

When field situations and space vehicles have permitted the introduction of minimally intrusive monitoring devices, it has been possible to develop sensitive observational methods that do not interfere with the subject's ongoing activities or bias the overall nature of the behavioral findings. These rely primarily on the oldest methods people use in evaluating one another - listening to what the participants say and looking at what they do.

When remote observers can obtain real-time or near real-time access to these data they can often detect trends in ongoing events.

The primary sources of potential in-flight measures are the visual, voice, systems telemetry, and hard data media shown in Table 8 (Ref. 20). These do not all permit real-time readout, or are they equally sensitive to all aspects of crew performance parameters. Flexible, broad-scope monitoring capabilities should be developed to optimize adaptability to changing situational needs.

Behavioral information should be based primarily on real-time or near real-time observation and recording of astronaut activities inflight. To minimize possible intrusions, little or no special activities should be required of the astronauts. Data should include: (a) measures of modes of interpersonal interaction and personal adjustment, derived from direct observation of astronaut activity, location, speech, meal, work and recreation patterns; (b) measures of emotional status, and (c) measures of living and work patterns, both derived from direct observations and self-reports.

Examples of objective measures to be collected in near real-time by behavioral observers are identified in Tables 9 and 10.

One measure of significant value is the specific-event and status record (Table 9). Each man's location in the spacecraft is periodically noted within designated function-specific areas.

Records of astronaut activity allow detailed objective evaluation of work-rest cycles, activity patterning across the waking hours, interactions with others, and time allocated by each man for leisure. If unrealistic time-lining models are used on long duration flights, the crew's abilities to adhere to such time-lines can be measured sensitively and unobtrusively and permit real-time adjustments to be made.

Patterns in overt communication (Table 10) among the crew members and between the crew and ground control are also behaviorally important. Trends in personal reactions to

TABLE 8

ONBOARD PERFORMANCE DATA MEDIA AND GROUND READOUT TIMES

ONBOARD DATA MEDIA	TIME OF READOUT BY GROUND STATIONS
A) VOICE TELEMETRY	REAL-TIME (CONTINUOUS)
B) VIDEO TELEMETRY	REAL-TIME (PERIODIC)
C) MONITORING INSTRUMENTS (MAN/SYSTEMS/ENVIRONMENTS)	REAL-TIME/DELAYED (DEPENDING ON PRIORITY) (e.g., BIOMEDICAL)
D) VOICE TAPES (DOWN-LINK)	DELAYED/POST-FLIGHT
E) VIDEO TAPES (DOWN-LINK)	DELAYED/POST-FLIGHT (POSSIBLE, BUT NOT YET PROVIDED)
F) PHOTOGRAPHIC FILMS	POST-FLIGHT (POSSIBLE DELAYED INFLIGHT READOUT, IF ONBOARD PROCESSING CAPABILITIES ARE PROVIDED)
G) HARD DATA AND SPECIMENS (e.g., WRITTEN LOGS/ SOIL SAMPLES)	POST-FLIGHT (LEAST SUITABLE FOR INFLIGHT ANALYSIS; BUT POSSIBLE)

NOTES:

1. VOICE, VIDEO AND FILMS CAN GIVE INFORMATION ON UNPREPARED SCENES, EVENTS, OR INSTRUMENTAL READOUTS (GRAPHIC OR NUMERICAL).

2. TIME DOMAINS SHOWN ARE THE QUICKEST FOR EACH MEDIUM. ANY OF THEM WILL PERMIT LATER ADDITIONAL READOUTS, IF PERMANENT RECORDS ARE KEPT.

TABLE 9

SPECIFIC EVENTS AND STATUS RECORD*

LOCATION:	IN WHICH COMPARTMENT OF THE SKYLAB OR SPACE STATION IS EACH ASTRONAUT AT A GIVEN TIME, AND WHERE IS HE LOCATED WITHIN THAT COMPARTMENT?
ACTIVITY:	WHAT IS EACH ASTRONAUT ENGAGED IN? POSSIBLE ALTERNATIVES INCLUDE:

a) DIRECT SCIENCE (OBSERVATIONS, DATA RECORDING)

b) SCIENCE SUPPORT (PREPARING EQUIPMENT, READING MANUALS, ANALYZING DATA, ASSISTANT TO ANOTHER ASTRONAUT IN HIS RESEARCH)

c) SPACE OPERATIONS (VEHICLE MANEUVERING, STATION KEEPING)

d) VEHICLE UPKEEP (HOUSEKEEPING, MAINTAINING, REPAIRING)

e) SELF-MAINTENANCE (EATING, CLEANSING, SHAVING, SLEEPING, NAPPING, RESTING, ANYTHING KEYED TOWARD CARING FOR ONE'S OWN PERSON)

f) MAINTENANCE OF OTHERS (COOKING, SERVING MEAL, CLEANING UP FOR OTHERS)

g) RECREATION (SOLITARY, SOCIAL)

h) IN TRANSIT

---

* FREQUENCY OF DATA COLLECTION SHOULD BE HIGH, PREFERABLY ABOUT ONCE EVERY 5 MINUTES

TABLE 10

ASTRONAUT COMMUNICATIONS RECORD

COMMUNICATION CATEGORIES:	WHAT IS THE COMMUNICATION STATUS OF EACH ASTRONAUT? POSSIBLE ALTERNATIVES INCLUDE: a) NEITHER TALKING NOR LISTENING b) TALKING c) LISTENING
INVOLVED PARTIES:	a) WHO INITIATED THE CONVERSATION? b) WHO WAS INVOLVED IN THE CONVERSATION? (MISSION CONTROL? ANOTHER ASTRONAUT? A GROUP OF ASTRONAUTS?) c) WHO LISTENED MOST? d) WHO TALKED MOST?
QUALITY OF COMMUNICATION:	a) WAS THE MAJORITY OF TIME SPENT IN DISCUSSING OPERATIONAL OR SOCIAL TOPICS? b) WAS THE CONVERSATION ARGUMENTATIVE OR INFORMATIONAL?
LENGTH OF COMMUNICATION:	ONLY IF IT LASTS MORE THAN A MINUTE OR SO

mission conditions, stress, group role changes and crew-ground relations can be derived from this information.

Similarly, mealtimes have been found to be one of the most socially important times of the day for many isolated crews (Ref. 25) and behavioral patterns during these times can provide information on many of these trends.

Finally, ground monitors should also keep a general qualitative log which allows written comments and supplementary data on unusual, important, or disturbing events. Factors such as crew comments, possible disputes within the crew or between the crews and ground teams, unscheduled or unusual events, times at which privacy was sought, etc., should be included.

These procedures were carried out in the Tektite I and II behavioral programs with pre-categorized IBM cards (Ref. 22) and near-continuous visual observation of individual and group activities. The use of machine-readable punched cards allowed rapid turn-around time in data summary and analysis (Ref. 23).

Even greater convenience can be gained by using more sophisticated devices to record behavioral data, such as real-time encoding on paper tape (Ref. 24) or an on-line computer or time-sharing facility. Recent innovations in computer hardware permit data to be handled efficiently on-line, viewed via display units, and analyzed moments after input. Such a monitoring system, coupled with the methodology described, could provide a high yield of informative data on the psychodynamics of man in space.

A similar inflight monitoring system could be provided. Aboard the spacecraft TV cameras would provide continuous coverage of work and social areas, but not of spaces designated as private, such as bunk and personal hygiene areas. Open microphones would monitor on-going conversations, although they could be switched off at the crew's discretion. Ground-based behavioral observers would monitor the incoming audio and video channels, encode behavioral information, and feed it to a waiting computer by keyboard or light pen entry.

The principal investigators would employ the same monitoring channels for on-line analyses and potential mission support. Upon command, tested analytic programs can be made available to evaluate ongoing trends. Results can be periodically CRT-displayed, or printed, either in graphic formats or as quantitative summaries.

Post-mission analyses of inflight behavioral patterns and their interrelations with mission conditions and events can be made available for the design and support of future missions. Advanced statistical programs are presently available in the Manned Space Flight Data Processing System (Ref. 26). These include multivariate analyses, regression analyses, analysis of variance, factor analysis, and time series analysis.

2.5 Pre- and Post-Flight Behavioral Measures

Important ground-based information can be collected through questionnaires and laboratory tests administered before and after the mission.

The pre-flight and post-flight measures should include biographical inventories information considered predictive of overall performance within the mission; an inventory of social behavior, which can be used as a means of predicting behavior tendencies under socially stressful situations; tests which indicate the amount of perceptual independence from cues within the visual and gravitational fields (e.g. Rod-and-Frame); and various standard personality inventories of interests, attitudes, and dispositions.

2.6 Inflight Performance Measures and Methods

Performance variations during prolonged missions can occur as a result of both intrinsic and extrinsic factors. Intrinsic factors include CNS arousal level and physiological status. Extrinsic factors include the characteristics of the stimulus field, the amount and type of training received, and the extent and compatibility of the supporting technology provided.

In-flight performance can be assessed by evaluating such parameters as task completion speed, task completion accuracy, metabolic cost and usage of systems consumables (Ref. 12). Long-term trends in these factors are also of interest since they can revela changes in skill retention. For maximum value, inflight performance evaluations should be based on a balanced variety of measures that do not overemphasize tasks that are either very simple or prohibitively complex.

To establish criteria for data evaluation, the present approach is to use each astronaut as his own statistical control, by gathering baseline data on the ground and comparing them with inflight data under operational conditions and progressive durations. Such individual "calibration" maximizes the ability to detect and and interpret small changes and time-trends in the relevant factors.

Sensitive diagnostic and predictive information may be derived from instrumented test tasks in operational space situations. The advantages of availability and situational control are similar to those of ground-based studies. However, the ability to extrapolate performance data from artificial tests to operational tasks is limited, and crew time-lines must be flexible enough to accomodate these additional measurements. Some aspects of performance may be observed and measured during the execution of real operational tasks without depending on test tasks. Such monitoring will provide the most valid operational data for post-flight analyses of any operational situation. However, its passive dependence on available events and activities may mean that appropriate data for status assessments within an ongoing mission will not be available when needed. The design of past systems has generally not permitted in-situ data acquisition equivalent to that available in ground facilities and thus restricted this approach to relatively gross and infrequent measurements.

The primary data sources for monitoring and evaluation of inflight performance trends are the audio and visual channels previously described for behavioral observations. These are complemented by two other major types of data: (1) biomedical, and (2) telemetry of environmental conditions and systems activities. Actual duration, accuracy, metabolic cost and results of all scheduled crew tasks can be compared to criteria based on ground simulations. For safety considerations, emphasis is placed on monitoring hazardous activities such as EVA. But all manned activities, regardless of their other mission objectives, can be sources of experimental information since they inherently test the adequacy of time-line scheduling, astronaut training, operational procedures, man-machine interfaces, supporting systems design, and the effects of flight conditions on man and machine performance (Ref. 20). Such non-interfering data on operational effectiveness may be supplemented by use of onboard simulators. These may be useful to promote inflight skill retention through practice and evaluation of selected tasks, without requiring the actual spacecraft systems to be taken off line for such purposes. Portable inflight test instruments may also be developed to provide laboratory type measures of basic skill components under IVA and EVA conditions without modification of spacecraft hardware (Ref. 31). Broad scope tests of such laboratory type measures will be available within the IMBLMS systems. Where systems telemetry is available for such critical operational activities as spacecraft maneuvering, these non-interfering operational data would be available for monitoring the state of both the crew and the vehicle, as indicated below.

Finally, the following inflight measures should be obtained, analyzed, and made available for real or near-real time monitoring support:

a. <u>Sensory/Cognitive/Psychomotor Performance</u>: Present techniques for assessing crew proficiency and performance characteristics in ground-based mission operations can be refined for inflight use. One passive technique (Ref. 32) employs telemetered data from key engineering subsystems while they are operated by the crew, and evaluates such parameters as time, accuracy, and performance efficiency.

   Figure 2 is an example of actual mission relations between pilot performance and systems responses. It shows the Apollo CSM yaw maneuver during manual change to a 45-degree out-of-plane attitude for CSM separation prior to reentry and subsequent yaw back to the inplane attitude. The figure indicates the pilot's stick displacements of the Rotational Hand Controller (RHC) while performing the maneuver and the empirical ratio (FM=Figure of Merit) of the actual fuel consumption to the theoretical minimum for each attitude change, (Ideal FM=1.0). A significant feature is the relative comparison of the two 45-degree yaw maneuvers under different vehicle configurations and thruster firing patterns. The initial 45-degree yaw of the CSM was performed very efficiently under conditions familiar to the individual, as reflected by the plots of attitude change, RHC manipulation and the relatively low Figure of Merit of 1.31. The return yaw of 45-degrees indicates less precision as a result of the new control dynamics following separation. This is best evident in the plot of RHC manipulation and the higher Figure of Merit of 2.60.

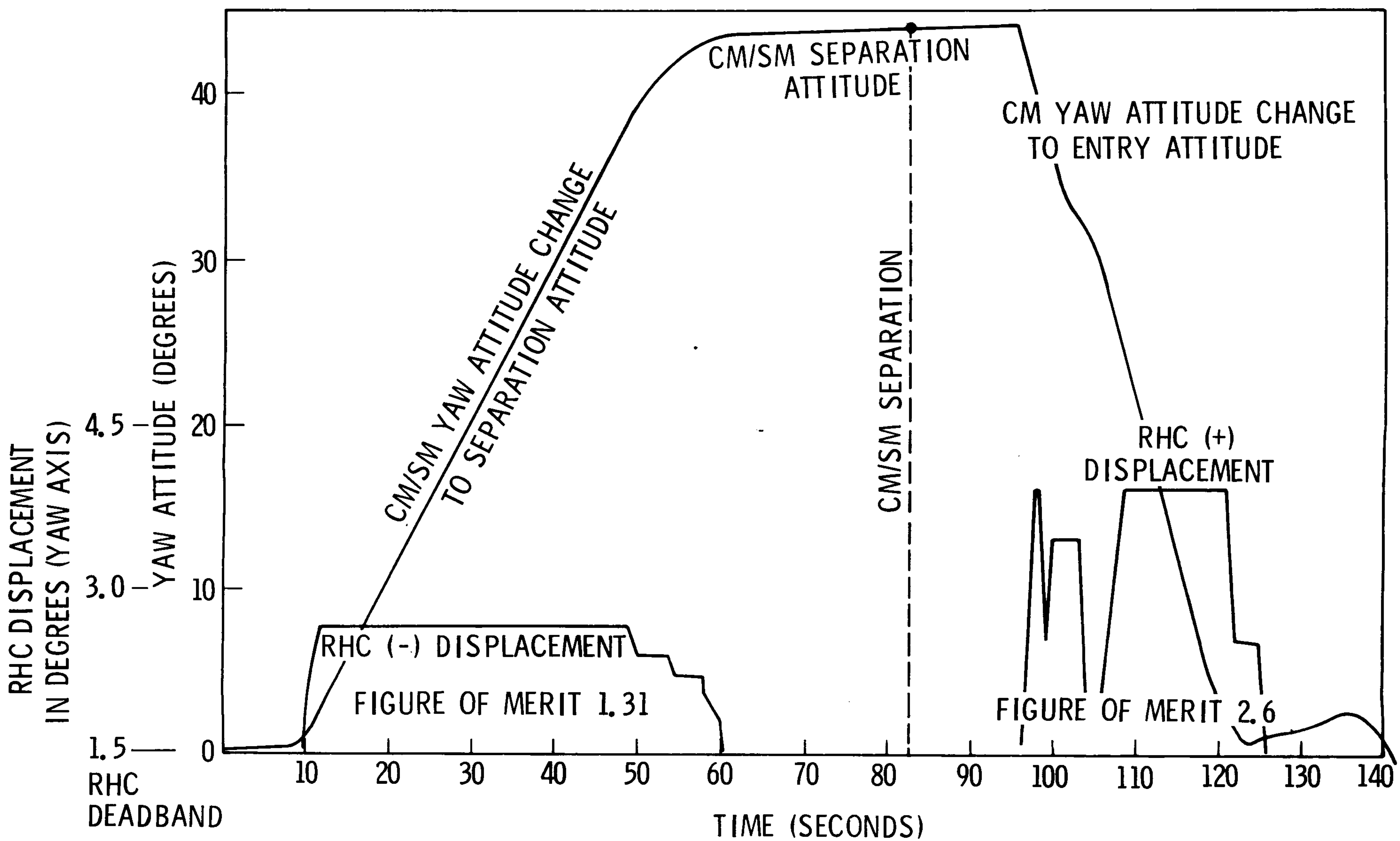

FIGURE 2 - FORTY-FIVE DEGREE YAW MANEUVER TO SEPARATION ATTITUDE

Such use of systems telemetry can reveal sensitive long-term trends in efficiency, quantify the fidelity of simulation techniques, and help evaluate crew skill status for crucial operations scheduled after long periods of time (e.g. separation and reentry maneuvers).

For this measurement technique to be possible, the next generation of manned space systems must be appropriately designed to provide man-machine performance information. The operational tasks instrumented for assessment studies must be sensitive enough so that possible decrements can be detected early, repetitive enough so that learning or unlearning trends can be easily revealed, and sufficiently representative so that they cover the expected range of crew activities. Specific measurements cannot be selected, however, until the operations and the activities profile of post-Skylab A missions are defined. When use of actual operational systems for diagnostic or training purposes is not compatible with mission constraints, supplementary onboard simulation and training devices with telemetry capabilities should be provided to assure timely feedback of performance status.

b. Metabolic cost: Ergometric measurements should be used to determine time profiles of both energy expenditure and exercise capacity during calibrated workloads, under suited and non-suited conditions. Energy expenditures should also be measured during performance of selected real intravehicular and extravehicular tasks, representative of the range of physical workloads. These measurements are identical to those proposed earlier under Crew Physiology.

c. CNS arousal level: The level of central nervous system arousal is related to the significance or intensity of the stimuli eliciting the response. Consequently, sensitive measures of arousal permit evaluation of human stimulus-response relationships when the temporal-spatial characteristics of the stimulus field can also be determined.

Physiological indices of arousal include galvanic skin resistance, electromyography, electroencephalography and visual sampling behavior. The first three have already been discussed so that nothing needs to be added here except that electroencephalography offers perhaps the most sensitive measure of arousal, and non-interfering methods should be developed to permit its use as an index of response status. Obviously, the interpretation of the derived data will depend critically upon the availability of concurrent information on mission events.

Visual sampling behavior (e.g. systematic eye movements across multi-target fields) has been found to correlate strongly with performance quality in surveillance tasks (Ref. 33). This index has already been used during four Mercury flights (Ref. 34). Several techniques for monitoring visual sampling behavior are now available, some of which are non-invasive and non-interfering during normal operations from fixed work locations (Ref. 35). Here again, data interpretation depends upon the availability of stimulus field correlates.

d. Time and motion dynamics. The audio and visual channels available for the behavioral program can also be used to record sequences of selected inflight activities so that time profiles of nominal and critical psychomotor tasks can be more sensitively analyzed. The great advantages of audio and video data are their rich potential for a broad range of information not derivable from pre-selected events or pre-rigged instruments and their relative freedom from constraining the activities being studied.

e. Differential diagnostic tests. If performance problems occur but their causes are not immediately evident, then differential diagnostic tests will be required to clarify contributory failure modes. These tests should include primary evaluations of perceptual, cognitive and psychomotor capabilities under controlled-test conditions (Ref. 36). Their interpretability will depend on availability of normative ground-based and inflight baselines.

2.7 Pre- and Post-flight Performance Measures

Ground-based preflight simulations should be conducted for all mission activities. Real-time, whole-task studies should emphasize such areas as EVA, vehicle maneuvering, payload deployment and use, and systems maintenance and repair.

These simulations will help train the crew, identify and correct man-machine interface inadequacies; and provide preflight estimates of performance capabilities.

Post-flight test measures will provide ground-based data on skill recovery profiles for those characteristics exhibiting inflight changes, and permit in-depth investigation of previously unidentified problem areas. They may also be used to obtain multiple concurrent measures not feasible under hazardous operational conditions, such as EVA.

Parallel analytic efforts should be devoted to the development of qualitative and quantitative models for the description and prediction of variations in man-machine-task-environment parameters. These will refine available estimates, calibrate inflight results, and assist in the design of future man-systems interfaces and functional tradeoffs.

Debriefings will provide information on the crew's subjective reactions to operational conditions, and on performance aspects not recordable by available instrumentation, to aid in the interpretation or clarification of flight data.

3. RESEARCH AND DEVELOPMENT

The ground-based and in-flight research and development efforts within this program are mutually supportive and interdependent. It is not possible, safely, economically or ethically, to test all possible combinations of factors related to biomedical, behavior and performance uncertainties under actual space conditions. Within the limits of available resources, ground-based analytical efforts, simulations and empirical studies must identify anticipated effects and be used to develop appropriate flight procedures and technology. In-flight observation, comparison and testing are essential for the verification, improvement and calibration of these ground-based estimates and methods. The diagnostic and predictive values of either ground or flight data alone are considerably lessened unless knowledge of these relationships is developed.

The following sections outline the in-flight and ground-based contributions to the combined objectives of developing our capabilities for optimizing man-systems design and support.

3.1 In-flight Investigational Aims

Behavioral Effects

0

1. Identify and evaluate long-term subjective reactions to physical isolation and confinement under spaceflight conditions.

2. Evaluate the nature and extent of inflight perceptual changes and the time course of their effects on earth-based nominal activity patterns.

3. Investigate changes in the support effectiveness of individual and group recreational activities (such as reading, games and listening to music) under the combined stresses of long-term spaceflight.

4. Study patterns of crew's uses of onboard areas for individual privacy and for group social activities, to evaluate changes with time and mission events.

5. Characterize the types and amounts of behavioral and motivational support sought by the flight crews from ground sources (such as family, friends, ground-support teams) over the time course of long-duration missions, and the effectiveness of such interactions.

6. Evaluate the effectiveness of existing monitoring techniques (on-line video, voice, and self-reports) to provide sensitive time profiles of behavioral changes with minimal intrusiveness.

Performance Effects

1. Identify and evaluate long-term functional reactions and changes in skilled operational performances (speed, accuracy, metabolic costs) under the combined effects of weightlessness and long-duration mission conditions.

2. Investigate the time course of changes in skilled task components of major psycho-sensory modes (visual and auditory stimuli, manual and whole body tasks).

3. Evaluate the differential efficiency of crew performance capabilities under IVA and EVA conditions as a function of mission duration, task conditions, and changes in crew medical status.

4. Establish the effectiveness of scheduled work-rest cycles in maintaining crew task performance levels under zero-g spaceflight conditions, and the abilities of flight crews to adapt to changes in time lines over long-duration missions.

5. Determine the effectiveness of zero-g work aids in keeping IVA and EVA work capabilities within optimal levels of (a) energy cost, (b) speed and accuracy, (c) comfort, and (d) other stress indicants.

6. Characterize the extent to which skill retention can be optimized by information exchanges between flight crews and ground-support teams, and the effects of long-term weightless conditions on unpracticed tasks requiring skilled coordination (flight maneuvers, re-entry tasks).

7. Evaluate the effectiveness of existing real-time and delayed monitoring techniques (video, voice, still photography, self-reports, instrumented systems telemetry) to provide sensitive time profiles of operational performance characteristics with minimal interference.

8. Evaluate the effectiveness of inflight countermeasures for providing relief of observed zero-g task performance changes, if undesirable decrements occur in specific skill components.

9. Investigate differential flight performance changes attributable to individual astronaut factors (differences in age, sex, prior training, exposures to flight stresses).

3.2 Ground-Based Definition Studies, Development Activities and Investigative Aims

Behavioral Factors

1. Study effects of prolonged small-group confinement and isolation, to evaluate the types of personal and interpersonal problems that can occur (e.g. perceptual satiation, demotivation, withdrawal, boredom, irritiability, friction, etc.).

2. Study small-group social dynamics relevant to all-male, all-female, and mixed crews.

3. Determine most effective countermeasures for preventing or controlling interpersonal conflicts, (e.g. by means of group discussion sessions, environmental variability, recreational facilities).

4. Identify individual and group personality characteristics that contribute to group cohesiveness, and those that tend to disrupt group integrity.

5. Study patterns of formal and informal group leadership and interpersonal relations.

6. Identify the effects of variations in "human density" or "volume per man" on personal adjustment and interpersonal relations.

7. Define and implement a comprehensive in-flight behavior observation program to establish the effectiveness of ground-based simulation methods, and define sets of reliable monitoring methods, predictive indices, and situational measures of personal adjustment.

Performance Factors

1. Identify and evaluate the effectiveness of monitoring methods and devices capable of providing sensitive measures of IVA and EVA performance characteristices with minimal task interference.

2. Investigate human psychosensory performance parameters, to develop information bases (response times, input-output characteristics) needed to (a) optimize the design of man-systems interfaces, and (b) efficiently allocate man-machine functions within long-term missions to flight crews, ground personnel, or machine systems.

3. Develop a variety of zero-g work-aids (tools, restr restraints, mobility aids) and procedures to optimize human performance capabilities in suited and unsuited modes, and under IVA and EVA conditions.

4. Identify potential performance variations attributable to individual astronaut characteristics (differences in age, sex, experience, transient fatigue or illness, exposure to environmental stressors).

5. Develop auxiliary techniques and systems (such as teleoperators) to supplement human task capabilities and overcome situational limitations or hazards.

6. Develop techniques for evaluating and alleviating inflight degradations in performance associated with environmental stresses or biomedical derangements.

Astronaut Selection

1. Develop selection criteria (identify and validate personality, professional and motivational factors important for personal adjustment to long-term space flight).

2. Investigate possibility of female astronauts, and identify appropriate selection criteria.

Astronaut Training

1. Define crew training and data-base requirements for:

   i. Biomedical/behavioral experimentation, and

   ii. In-flight medical care

2. Investigate impact on astronaut personal life of sequences of intensive training that are followed by prolonged space missions. Identify ways to minimize potential problems.

3. Define types of simulation required to study effects of prolonged space flight conditions (both nominal and contingency) on physiology, behavior and performance.

4. Develop simulation situations where the combined stresses of prolonged space flight are artificially enhanced, to induce reactions on an accelerated-time basis.

5. Develop basic measures of behavior and performance capable of ground-based and inflight assessment, to permit the quantitative and qualitative calibration of ground-based simulation techniques and enhance predictive sensitivity.

Flight Crew Selection and Training

1. Define compatability criteria and skill mixes for male, female, and mixed crews.

2. Define minimum and optimal physical status requirements for long-duration flight readiness.

3. Investigate potential within-mission changes in formal authority structures among flight crew members for their effects on combined operational-scientific objectives and crew-rotation planning.

4. Develop criteria for training programs to enhance crew compatibility, team task-effectiveness and increase their resistance to the stresses of long-term missions.

Habitability

1. Develop improved techniques and equipment for body cleansing, shaving, nail paring and haircutting in space.

2. Develop techniques and hardware for the laundering of clothes and cleansing of the habitat areas in space.

3. Develop means to aid crew housekeeping (e.g. laminar airflow, adhesion, suction, magnetic retention, etc.).

4. Refine nominal work-rest cycles and contingency guidelines, and establish minimum continuous sleep requirements.

5. Establish and develop adequate recreation facilities, recreational hardware and spacecraft configuration requirements.

6. Define ranges for sensory stimulation, variations in decor, illumination, furnishings, and acceptable operational aspects of personal hygiene and waste management systems.

7. Identify the probable effects of lack of habitual sexual contacts during prolonged (planetary) missions, on individual and group behavior and performance.

PROGRAM PLANNING GUIDELINES

The biomedical program of NASA should be designed to support two broad types of objectives. First, the development of a real-time system of data analysis and decision-making to assure the greatest possible crew safety and mission success. Secondly, the acquisition of information about man's abilities, limitations and characteristic reactions which is necessary before future missions of longer durations can be planned and controlled. It is expected that the fundamental knowledge of the human organism gained in this program will be useful to general medical practice.

The Skylab medical experiments are in the second category, but little development work has been oriented toward a real-time system supporting mission control. In the flight situation, the mission controller's primary purpose is to insure crew safety and mission success. To do this he must have real-time information of the following four basic types:

1. Detailed state of the spacecraft and its subsystems.
2. Physiological state of each crew member.
3. Current performance capabilities of the crew (e.g., neurological responses, crew interpersonal behavior, efficiency of task performance).
4. External disturbances (e.g., solar flares).

The need for obtaining all of these types of information is apparent from Figure 3, which shows the basic control logic for the flight situation. The monitoring system for long-duration flights should be designed to supply this data to the mission controller, R_2, in a form adequate to make go/no-go decisions at critical stages of the mission. The ability to make these decisions requires that R_2 have a working model of how the four types of information relate to crew safety and mission success. The model should explicitly recognize that each crew member serves as the controller, R_1, of his own internal and external environments (i.e., physiology and most man-machine interfaces). Mission control, R_2, must

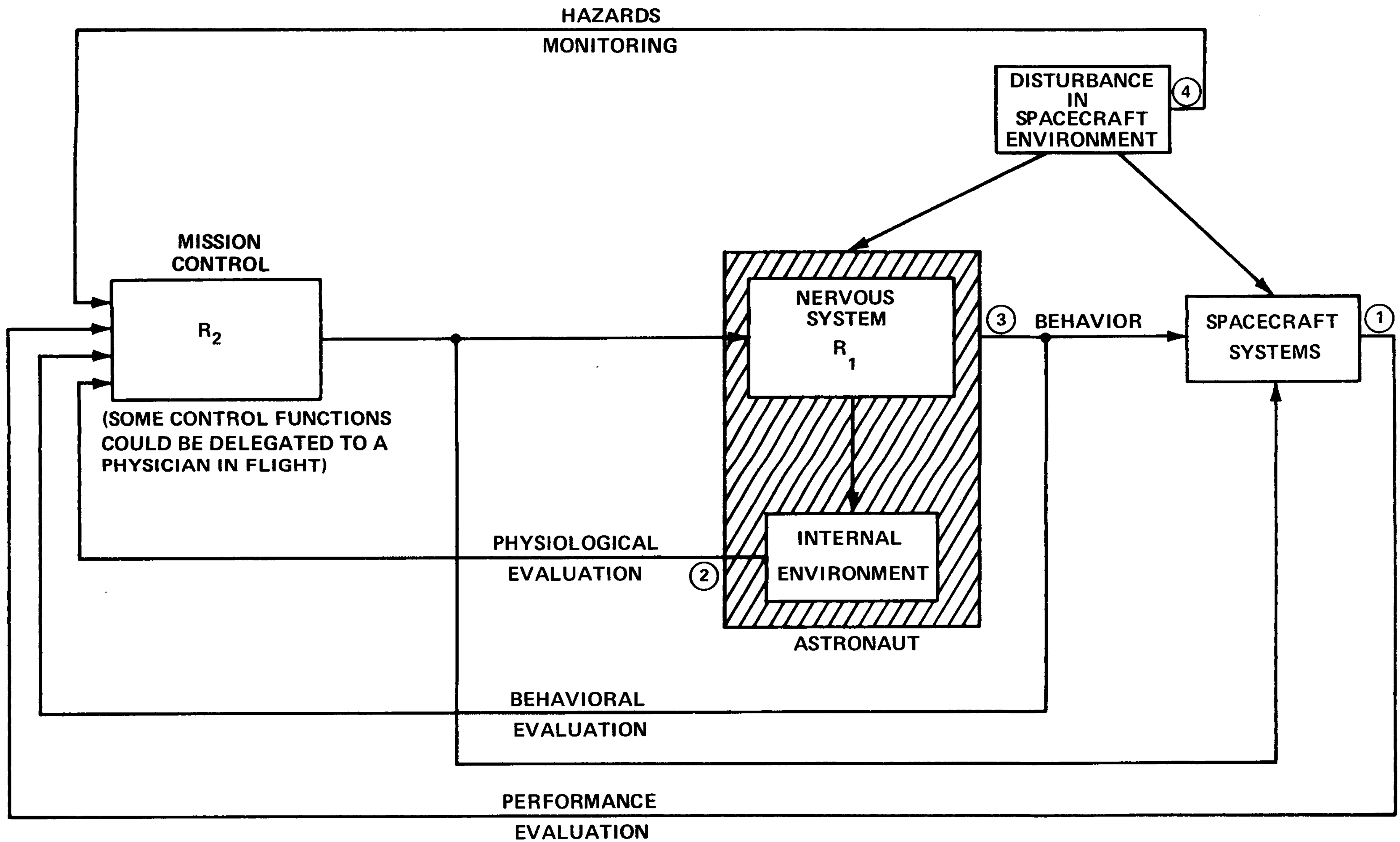

FIGURE 3 - BIOMEDICAL CONTROL DURING MANNED SPACE FLIGHT

be able to assess and predict the condition of R_1 so that each alternative future course of action can be evaluated before deciding to enter the next phase of the mission.

Neither this kind of model nor the monitoring systems necessary to supply its inputs presently exists, either within the agency or anywhere else, although both are curcial for long term operational missions. The current Apollo missions do gather extensive information of type 1 (spacecraft systems), but heart and respiration rates provide the only continous behavior/performance information sources. The Crew Time-line Assessment Information System (Ref. 32) has provided performance information via post-flight analysis of some systems-crew interfaces, but it has not yet been adapted to gather information during flight.

The development of the kind of model of man's internal and external functioning shown in Figure 3, and the search for the best combination of indices (both physiological and behavioral) to use in the flight situation for assessing the state of each crew member could serve as the bases for building a significant biomedical program. Ground-based experiments will be needed to provide missing links in the model, and theoretical work will be needed to construct a model of the proper depth and extent for use in flight situations. If the monitoring system is designed solely to feed into the model, the past difficulties of being swamped with too much data of the wrong type will be avoided.

If a difficulty arises in the flight situation, definite sequences of diagnostic steps are carried out, either consciously or unconsciously. The logic of these real-time diagnostic procedures is shown in Figure 4. From such analyses it becomes clear that real-time safety considerations may require operational decisions based on limited diagnostic data, and inflight monitoring and testing may be curtailed by limited facilities or time.

The second broad objective mentioned at the beginning of this section is the identification of basic limitations of man in long-duration space flight. This problem has been approached empirically in the past and no change in that approach is necessary now. We cannot predict with any confidence the combined reactions of the many complicated systems of the body to long durations of

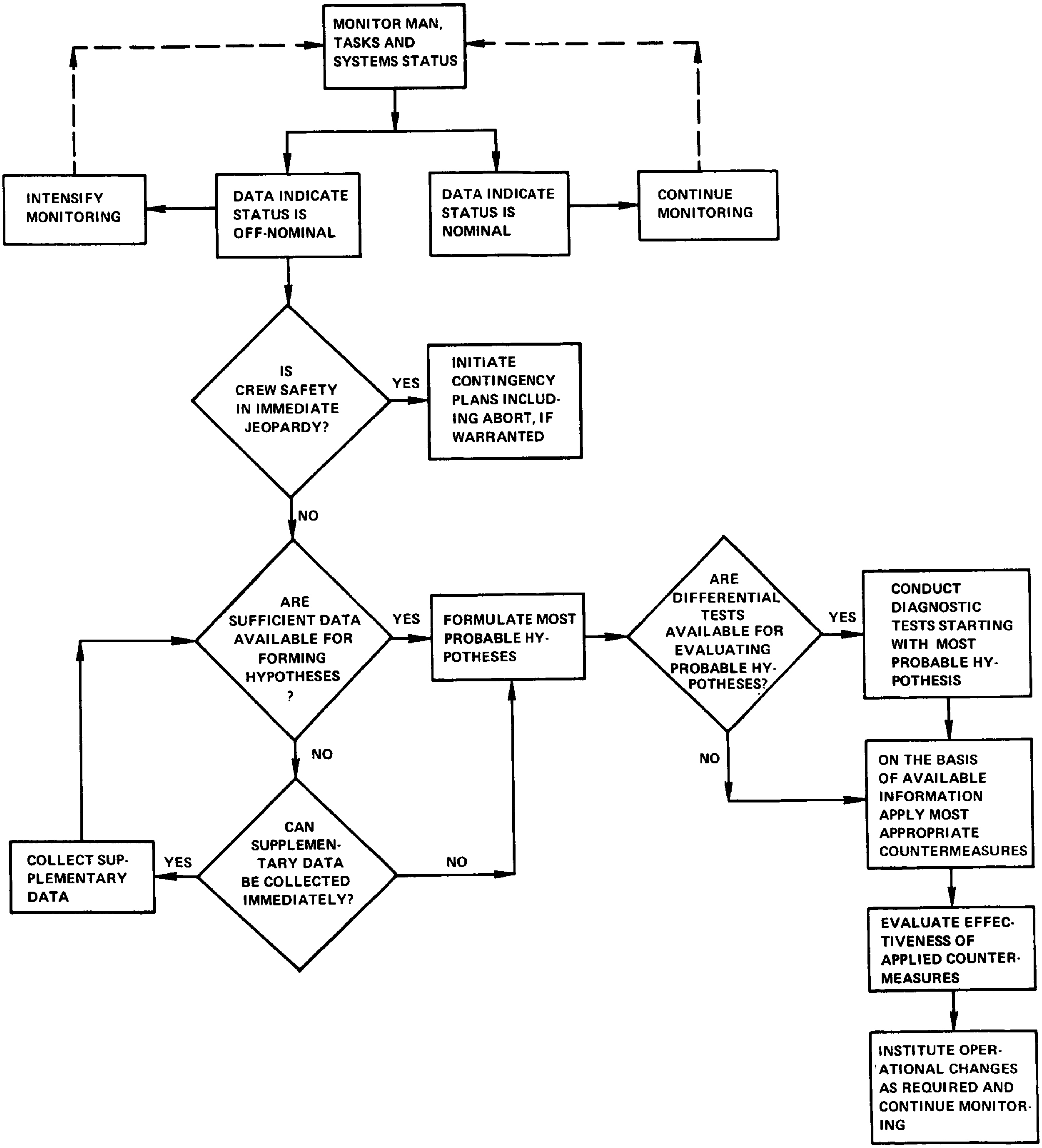

FIGURE 4 - REAL-TIME DIAGNOSTIC LOGIC

weightlessness. Therefore, the strategy for extending flight duration should be to extend the flights in gradual increments (Ref. 1) and watch closely what happens to the systems of the body which have shown effects in previous flights. Alternative strategies are being considered (Ref. 2). The decision to extend mission duration can be based on data from pre- and post-flight physical examinations in previous missions. The past approach for extending mission duration has been in steps which double the nominal duration. This will continue through the 56-day Skylab flight.

If even one crew member encounters significant problems attributable to the flight exposure, causative factors must be understood and countermeasures established before attempting a longer mission. It is reasonable to require a physician to be in the crew for all missions longer than six months. Before a planetary mission is attempted, a trial mission in earth or lunar orbit with comparable crew size, vehicle configuration, and mission length should be required.

Artificial gravity has been suggested as a means of preventing physiological deconditioning, improving habitability and preserving crew work effectiveness. However, rotational effects could produce additional problems as numerous and severe as the problems of weightlessness (Ref. 9). Therefore, efforts should be aimed at validating alternatives to artificial gravity, such as chemotherapy and zero-g work aids, rather then requiring artificial gravity as an operational necessity. A logical scheme for deciding how to implement artificial gravity or its alternatives is shown in Figure 5.

1. Integrated Medical and Behavioral Laboratory Measurements System (IMBLMS)

A comprehensive review of all basic physiological and behavioral measurements which are applicable to space flight is being carried out under the IMBLMS program. The IMBLMS is a system which has the range and flexibility to include all or a selected portion of the measurements listed in Table 11, depending on the particular requirements of the biomedical program for a given flight. This system will be ready to fly after the Skylab program and will be available for use in all manned missions thereafter. The table indicates which measurements are planned for the Skylab program. The measurements not marked with a circle

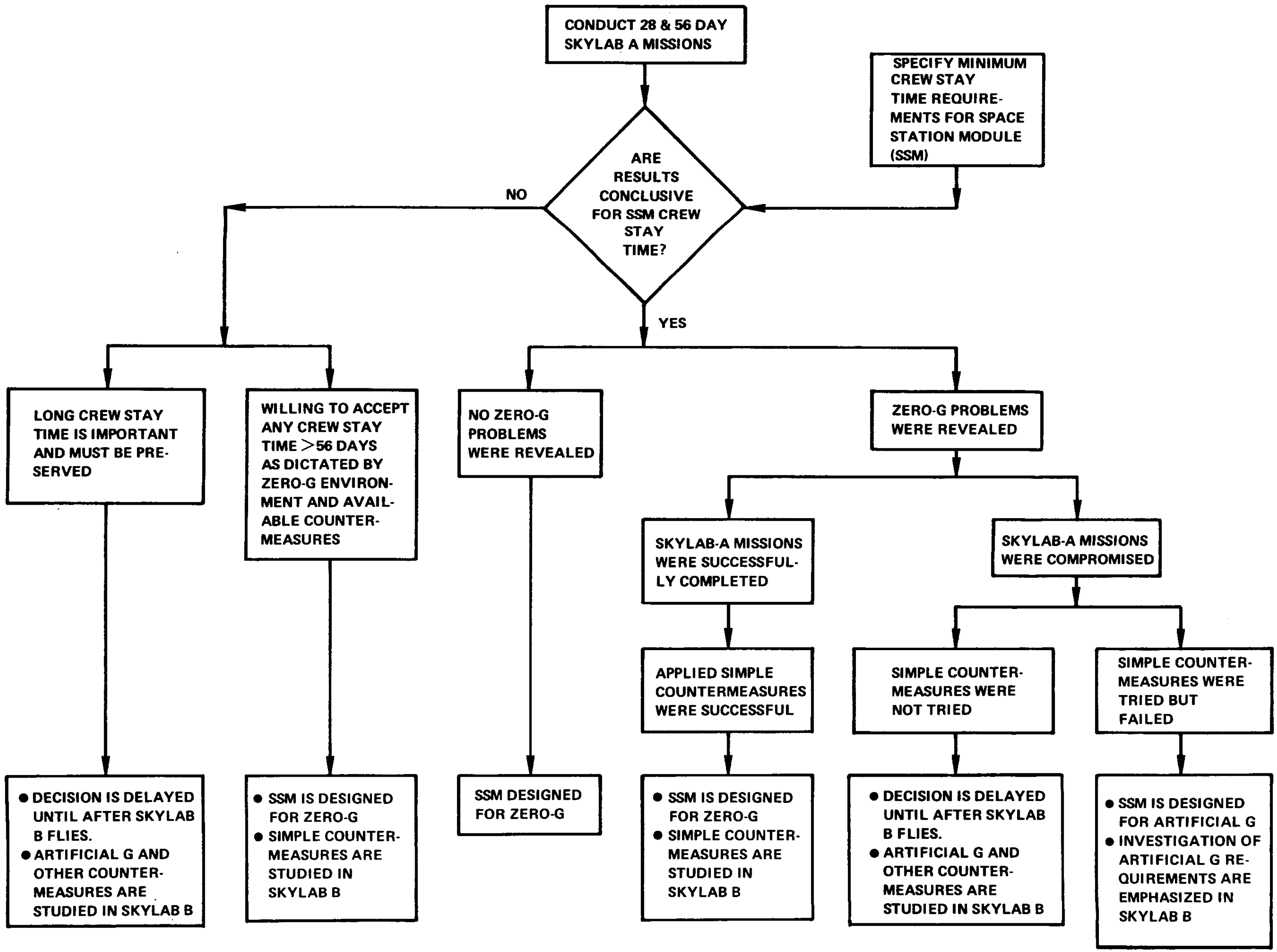

FIGURE 5 - ARTIFICIAL GRAVITY DECISION LOGIC

TABLE 11 - MEDICAL/BEHAVIORAL MEASUREMENTS IN IMBLMS AND SKYLAB EXPERIMENTS *

IMBLMS	SKYLAB MED/PERFORMANCE EXPERIMENTS																			
	M071	M072	M073	M074	M091	M092	M093	M111	M112	M113	M114	M115	M131	M132	M133	M151	M171	M172	M1[illegible]	M1[illegible]2
NEUROLOGICAL																				
Clinical Evaluation (include reflexes, sensory, and motor pathways)													□		○					
A-gravic Perception (Minimum restraint device)													○							
Ocular Counter-Rolling													○							
Oculogyral Illusion													○							
Visual Task with Head Rotation													○							
Electronystagmogram													○	○	○					
Angular Acceleration Threshold													○							
EEG														○	○					
CARDIOVASCULAR																				
Clinical Evaluation					□	○														
ECG (Frank Lead System)/VCG					□	○	○							○			○			
Phonocardiogram																				
Cardiac Output																				
Arterial Blood Pressure (BPMS)			□		□	○											○			
Venous Pressure - Peripheral			□		□	○														
Blood Volume and Fluid Compartments			□		□	□				□										
Regional Blood Flow					□	□														
Venous Compliance (LVMS)					□	○				□										
Arteriolar Reactivity					□	○														
Arterial Pulse Contour					□	○								○						
In-Flight Exercise (Ergometer Output)	○				□	○	○										○	○		
LBNP					□	○														
Elastic Leotards																				
Ballistocardiogram																				
Carotid Body Stimulation																				
Thoracid Blood Flow																				
Venous Pressure - Central (if necessary)																				
RESPIRATORY																				
Clinical Evaluation																				
Respiratory Rate																	○			
Lung Volumes																				
Pressure, Flow, and Volume (Airway Resistance)																				
Compliance - Lung or Total																				
Capillary Blood O_2, CO_2, and pH																				
Breath by Breath O_2 Consumption and CO_2 Production																	○			
Alveolar to Arterial Gradient																				
Diffusion Capacity																				
METABOLISM AND NUTRITION																				
Clinical Evaluation	□				□	□											○	○		
Energy Metabolism with various Levels of Activity	○				□	○											○	○		
Oral/Tympanic Temperature (BTMS)	□				□	○											○			
Skin Temperature (BTMS)	□				□	○											○			
Caloric Intake	○					□											□	○		
Body Mass (Thornton Technique) (BMMD)	○					□											○	○		
Muscle Size and Strength	□					□											□			
Fluid (including sweat)	□					□											□			
Nitrogen balance	□					□		□									□			
Mineral balance	□					□		□									□			
Electrolyte balance	□		□		□	○		□		□							□			
Urine Volume Measurement (USVMS)	○		□	○													□		○	
Wet Weight of Feces	○			○															○	
Return of Total Dry Stool	○			○																
Fluid Intake Measurement	○		□	○	□	○														
Return of all Food Packages	□		□	○						□										
Sweat Measurement and Sample Return	○																			
Total Body Water (Breatholater/Deuterium)			□														○			
EMG														○						
Bone Densitometry - Isotope Technique	□	□																		
Gastric Pressure and pH (Endoradiosonde)																				
Plasma Volume			□		□	□				□										
ENDOCRINOLOGY																				
Clinical Evaluation	□							□												
HEMATOLOGY																				
Clinical Evaluation								□		□	□	□								
Rumple - Leede								□				□								
RBC Mass - DFP^{32} or Cr^{51}					□	□		□		□		□								
RBC Survival - DFP^{32}								□		□		□								
MICROBIOLOGY AND IMMUNOLOGY																				
Clinical Evaluation																			○	□
Body Microflora (Bac., Viral, and Fungal)																			○	□
Environmental Culturing (Bac., Viral, and Fungal)																			○	□
BEHAVIORAL EFFECTS																				
Clinical Evaluation																○				
Sensory Test Battery																				
Perceptual Evaluation																				
Higher Thought Processes																				
Memory - Short and Long Term																				
Vigilance (operational tasks)																				
Learned Activity (Tracking and Reaction Time																				
Time and Motion Study																○				
Voice Communication (PCE)					□	○	○							○		○			○	
SPACECRAFT MEASUREMENT INTERFACES	○			○																
Data Handling																				
Data Processing																				

Legend: ○ = Inflight Measurement
□ = Pre and Post Flight Measurement

* FROM A PRESENTATION BY GENERAL ELECTRIC TO THE DIRECTORATE OF MEDICAL RESEARCH AND OPERATIONS, NASA/MSC ON OCTOBER 16, 1970

TABLE 11 (CONTINUED)

IMBLMS	SKYLAB MED/PERFORMANCE EXPERIMENTS																			
	M071	M072	M073	M074	M091	M092	M093	M111	M112	M113	M114	M115	M131	M132	M133	M151	M171	M172	M191	M192
Creatine and Creatinine - Urinary	□																			
Urinary and Fecal: N, Ca, P, Na, K, Cl, and Mg	□					○														
Mucoproteins - Urinary	□																			
Pyrophosphates - Urinary	□																			
Hydroxprolines - Urinary	□																			
Total Amino Acids - Urinary	□																			
Routine Urinalysis	□		□			○														
Total Protein - Plasma	□								□	□										
Protein Electrophoresis - Plasma	□								□	□										
Glucose - Blood (Inflight)								□												
Ca and PO_4 - Serum (probably Pi)	□							□												
Bilirubin - Serum	□							□												
Cholesterol - Serum (probably Pi)								□												
BUN (probably Pi)	□							□												
Uric Acid - Blood (Pi)								□												
Alkaline Phosphatase - Serum (probably Pi)	□							□												
pH, pO_2, and pCO_2 - Blood								□												
Bicarbonate - Blood								□												
CPK (Creatine Phosphokinase - Serum) (Pi)	□							□			□									
LDH and LDH Isoenzymes - Serum	□							□			□									
SGOT - Serum								□												
SGPT - Serum								□												
Aldosterone - Urine (Pi)	□		□					□												
ADH - Urinary and Serum (Pi)	□		□					□												
ACTH - Blood (Pi)	□							□												
TBPA (Probably Pi)	□							□												
17-hydroxycortiocontcroids - Urine and blood (Pi)	□							□												
17-Ketosteroids - Urine (Pi)	□							□												
VMA - Urine (probably Pi)																				
Metanephrines - Urine (Pi)			□																	
Catechols - Urine (Pi)																				
Histamine - Blood and Urine (Pi)								□												
5 Hydroxy indolacetic acid - Urinary (Probably Pi)																				
Blood Cell Morphology								□		□		□								
Reticulocyte Count								□		□		□								
Hematocrit								□		□		□								
Hemoglobin								□			□	□								
RBC Fragility (Osmotic)								□				□								
RBC Mass and Survival								□		□		□								
Bleeding Time								□	□	□										
Clotting Time								□	□	□										
Prothrombin Consumption								□	□	□										
Clot Retraction								□	□	□										
Lymphocyte Karotyping (probably Pi)								□	□	□		□								
WBC Mobilization (Rebuck Technique)								□	□	□		□								
Immunoglobulins and Fibrinogen									□	□		□								
Transferins										□										
Methenoglobin								□			□									
RBC Enzyme Studies (Pi)								□			□									
Complement Titration								□	□	□	□									
Antibody Titration								□	□	□										
Sulfate - Urinary																				
TSH (Pi)			□					□												
Growth Hormone (Pi)								□												
Thyroid Bound Globulin (T_3) (Pi)			□					□												
Parathyroid Hormone (Radio-immune Technique - Serum) (Pi)								□												
Parathyroid Hormone - Urinary (Nelson Technique) (Pi)																				
Calcitonin - Serum (Pi)			□					□												
Insulin Assay (Pi)																				
Glucagon Assay (Pi)																				
Serotonin (5 HIAA) - Blood (Pi)																				
Platelet Adhesiveness								□		□		□								
Fibrinolytic Activity								□	□	□										
Blood Rheology (REG)								□												
Blood Lipids								□			□									
Specimen Mass Measuring Device (SMMD)				○														○		
Angiotensin - II			□																	
Osmolarity	□		□									□								
Thoracic Pathology (X-ray)						□														
(Membrane Assay & Cytogenetic Studies)								□		□	□	□								
Suit, Cooling Garment Fluid Temperature																				
Suit, Pressure																				
Suit, Temp. & RH																				
Suit, pO_2 & pCO_2																				
Electromagnetic Field													○					○		
Acoustic Noise Vibration																		○		
Acceleration													○					○		
Ambient Temperature				○		○	○						○				○	○		
R.H.																	○	○		
Ambient Pressure						○	○										○	○		
Ambient Radiation Dose								○									○	○		
Ambient, pO_2, pCO_2																	○	○		
Light (Lux vs λ)													○							
Ambient Air Flow Rate																		○		

Legend: ○ = Inflight Measurement
□ = Pre and Post Flight Measurement

or square in Table 11 are new measurements made possible with IMBLMS but not done before in the biomedical program.

2. SPECIFIC GUIDELINES

The following spacecraft environmental parameters are representative of current design goals for U.S. manned spacecraft.

Artificial Atmosphere:

(a) 5 psia total pressure consisting of 70% O_2 and 30% N_2, or 7 psia total pressure consisting of 50% O_2 and 50% N_2 in the space cabin.

(b) 3.85 psia minimum total pressure pure O_2 under suited conditions or during emergencies.

(c) pCO_2 should remain below 5.4 mm Hg (nominal limit for continuous breathing), and should not exceed 7.6 mm Hg (maximum limit). In emergencies when partial pressures of CO_2 exceed 15 mm Hg, personal respiratory protective devices must be used.

(d) The 5.4 mm Hg continous CO_2 limit may have to be lowered if significant long-term effects on bone demineralization are discovered.

(e) Exposure levels to some atmospheric contaminants have been recommended by the National Academy of Sciences (Ref. 37). For contaminants not contained in this reference, a hundredth of their Industrial Threshold Values should be used (Ref. 38).

(f) Temperature should be adjustable between 75° ± 5°F and relative humidity between 40% and 70%.

Life Support Consumables:

(a) Balanced diet of 2500 calories per man per day, with allowance for individual preferences.

(b) 6.5 pounds of potable water per man per day.

(c) 2 pounds of oxygen per man per day.

Free Volume:

Minimum tolerance volume for missions longer than 60 days is estimated at 150 $ft.^3$/man. Adequacy range is estimated between 600 to 800 $ft.^3$/man for 4-6 man crew, with 1000 $ft.^3$/man considered optimal. Larger crews may require less volume/man.

Utilization of Volume:

(a) Nominal permanent volumes:

Work Unit 40%

Personal Unit 20%

Public Unit 25%

Service Unit (laundry, toilet, etc.) 15%

(b) Volumes may be capable of reconfiguration for alternative and multiple uses.

Spacecraft Architecture:

(a) Permissible length of an operational path should be inversely related to the frequency of its usage.

(b) Use unsaturated colors for work areas, and warm, saturated colors for recreation area.

(c) Maintain consistency of physical and visual directional orientations within each work area.

(d) Provide system of permanent restraints (in high work-density, resting and recreation areas) plus also portable, easily attachable personal systems. Avoid the use of hand holds as restraints in work areas.

(e) Mobility systems must incorporate provisions for preventing or damping tumbling and rolling. Low impact stops must also be installed in surfaces where bumps are likely.

(f) Storage pouches or canisters must be indexed and allow for expansion of bulk from prepackaged minimum.

Illumination:

(a) 20 to 30 foot-candles (supplementary spots to 100 foot-candles) white light in work areas.

(b) 15 to 25 foot-candles (spots to 50 foot-candles) white light in crew quarters and recreation areas.

(c) 10 foot-candles in service areas.

(d) Use color for visual variety and operational cueing.

Noise Level:

(a) 85 db. maximum for wide band noise and 75 db. for narrow band noise under continuous exposure conditions.

(b) Ear protection should be used whenever necessary, to provide attenuation to these levels.

Personal Hygiene:

(a) Provide for daily "sponge bath" plus frequent "whole body shower" in either a wet suit or steam bath enclosure.

(b) Provide for shaving with whisker collection capability plus hair and nail cutting devices also with debris collection provisions.

Clothing:

Use washable or disposable, lint free, chemically inert, flame, soil and tear resistant materials.

Duty-rest Scheduling:

(a) Aim for conventional 24-hour periodic schedules, with capability for simultaneous sleeping of whole or majority of crew for at least 6 to 8 hours.

(c) Duty scheduling and rest periods during work days should be based largely on mission needs. Table 12 shows the similarity of time utilization among men under various working and living conditions.

Recreation:

(a) Exercise should be used as a countermeasure to the effects of weightlessness and for preserving psychophysiological health.

(b) Recreational facilities should include provisions for sensory variations in audio (i.e., music) and visual modes, (i.e., books, films), and should take into consideration individual preferences. They should be sufficiently flexible to permit shifts in personal interests during long-term missions.

Man-Machine Trade-offs:

Tables 13-A, B, and C summarize human sensory, sensorimotor and mental functions along with potential applications of these functions in manned space flight experiments (Ref. 40).

Table 14-A and B list representative functions relevant to the majority of space flight experiments and identify a tentative choice for each man-machine allocation, with an indication of the basis for the choice (Ref. 41).

Assigned Work:

Work should be varied, meaningful and of importance to the astronaut in order to maintain motivation and efficiency. It should provide regular feedback of results and reasonable levels of complexity and structure. Extended periods of vigilant monitoring by crew should be avoided. Behavior or performance monitoring procedures can indicate changes in motivation levels. If these levels become low enough to effect task performance, assigned activities should be rescheduled or restructured according to individual needs.

TABLE 12

DAY'S TIME UTILIZATION IN HOURS AVERAGED OVER A WEEK

ACTIVITY	AVERAGE AMERICAN MALE[1]	TEKTITE CREW MEMBER[1]	SCHEDULED FOR 28-DAY SKYLAB[2]
Research (or at work)	6.0	5.6	8.6
In transit	1.4	0.2	---
Work tools maintenance and repair	0.9	1.9	1.5
Self-maintenance[3]	2.1	2.7	4.5
Recreation	4.5	3.1	1.4
Resting and sleeping	9.1	10.5	8.0

[1]Reference 19

[2]Reference 39

[3]Incluces meal preparation, eating and exercise.

TABLE 13-A

SUMMARY OF HUMAN SENSORY+RESPONSE CAPABILITIES AND RELATED FUNCTIONAL APPLICATIONS

Function	Nominal Characteristics & Limits	Major Applications	Special Limits
· Vision	· Acuity (Angular Thresholds) - General Target Detection ∿50% Probability: 0.8 Min. >99% Probability: 1.4 Min. - Minimum Separable: 0.4 Min. - Vernier: 0.03 Min. - Stereoscopic: 0.025 Min. - Minimum Perceptible: 0.008 Min. (All at Background Luminance of 100 mL.) · Sensitivity: 10^{-5} mL (Adapted) · Spectral Range: 397-723 mμ · Spectral Discrimination: 1 mμ at Sodium Line and at Constant Intensity · Critical Discrete Signal Rate: 50 cps Central } At >10 mL 20 cps Peripheral } · Ambinocular Field Coverage (Total area visible to either eye) - Head fixed, eyes not fixed · Horizontal 165° each side · Vertical 66° up; 82° down - Head fixed, eyes fixed · Horizontal 95° each side · Vertical 46° up; 67° down · General: Very sensitive, paired sensors - automatically coupled for stereo. Selective image fusion or automatic suppression of unwanted double images. Numerous automatic functions (aperture control, focus, tracking, signal response).	· Self-orientation · Discrete Target Detection · Target Fixation and Motion Compensation · Navigation · Target Selection - Selective Aiming · Pattern Recognition - Description - Comparison - Interpretation · Signal Detection in Noise · Color Evaluation - Color Correction · Photo Evaluation (Quality) · Photo Interpretation · Display Scanning · Stand-by Sensing - Warning lights · Low Light Observation · Motion Detection · Accurate Alignment · Recreation and Social Interactions	· Relatively high directional sensitivity - Highest acuity in central field - Highest color detection in central field · Overload Factors - Glare - Flash Blindness - Signal Rate · Low Light Vision - Decreased Acuity - Long Adaptation Time - Color discrimination and perceptual changes · Spectral Masking and Color Distortions · Empty-field Myopia · Illusions, Size and Depth Distortions · Afterimages · Vigilance Degrades with Constant Fields and Requires Sensory Variation
· Hearing	· Sensitivity: 2×10^{-4} Dynes/cm^2 at 1000 Hz · Frequency Range: 20-20,000 Hz · Frequency Discrimination: ±10 Hz at 500 Hz/56-64 Db · Field Coverage: Spherical with Moderate Directional Sensitivity · General: Sensors paired for stereophonic reception; several automatic functions including reflex tracking and noise suppression. Relative pitch (Frequency) matching is good, but Absolute Pitch Identification is not, and varies with training. Perception of pitch is a function of signal intensity. High frequency range attenuates with age and noise exposure.	· Discrete Signal Detection in Noise Fields - Pattern recognition - Intelligibility · Signal Scanning · Stand-by Sensing - Warning signals · Signal/Noise Adjustment · Frequency Matching · Beat Detection · Voice and Code Communications · Social Interactions	· Overload Factors - Hearing threshold shift - Frequency sensitivity attenuation - Signal rate · Frequency Matching with Signal Intensity Uncontrolled
· Chemical Senses	· Sensitivity (Thresholds) - Taste: 4×10^{-7} mol - Smell: 7×10^{-13} mol · General: Relatively high interaction between taste and smell. Thresholds vary widely with type and temperature of substance.	· Detection of Air, Water, Food Contaminants · Identification of Substances by Taste or Smell	· Relatively Slow Response and Recovery Rates · Both Senses Easily Squelched/Masked · Discrimination of Individual Stimuli in Mixtures Poor · Low Directivity · Identification of Stimuli a Function of Experience and Training · Noxious Odors Can Distract Attention and Induce Nausea

TABLE 13-B

• Kinesthesis, Proprioception and Position Senses	• Sensitivities - Acceleration: 0.1-0.2 deg/sec^2 Angular Acceleration with 10-15 sec. response for 75% correct detection of direction: 0.4 deg/sec^2 with 1 second response time (useful threshold). - Displacement from vertical in Zero-G: Lag of response 40-50 seconds. - Vibration: Tangential at fingertip: 10 Hz at 0.01 G, 800 Hz at 0.3 G • Special Functions - Stereognosis: Can determine shape by feel - Apply graded force - Assess force required	• Self-Orientation • Detect Random Motions • Detect Vibration • Manipulate Control with Calibrated Force • Identify or Describe Object without Visual Cue • Determine Resistance to to Deformation or Motion	• Slow Response to Low Rate of Onset of Motion • Slow Response to Displacement from Vertical in Zero-G - No response without visual cue • Proprioception limited in Zero-G - Weight, posture, skin pressure cues lost • Inner-Ear Sensors Relatively Easily Confused - Can Give False Information
• Somatic Senses	• Tactile: 0.5° × 10°/min. rate - Two point discrimination: • Fingertips: 2-3 mm • Body (Gen): 60-70 mm • Tongue : 1-2 mm • Pain: Not Readily Quantified • Temperature: (At Sensor) Decrease of 0.004°C/Sec. Increase of 0.001°C/Sec. • General: These sensors are present in the skin of the entire body, but distribution per unit area varies widely. Touch sensation is amplified in detection by movement of hair. Somatic sensors generally supplement proprioception and kinesthesis and contribute to fine, calibrated manipulations (along with small muscle proprioceptors).	• Sensing Surface Texture • Wet/Dry Sensing • Detecting Temperature Changes • Detecting Temperature Quality, Quantity • Very Fine Shape, Texture Discrimination • Detect Potentially Injurious Stimulus • Detect Inscribed Information without Visual Cue	• Sensors Adapt Quickly to Constant Low Intensity Signals • Perceptions are Readily Masked or Fatigued
• Sensorimotor Control	• Neuromuscular Response Time Total ~0.2 to 1.0 seconds (including perception, integration and activation times) • Reaction Time - Simple: 0.2 to 0.3 seconds - Reasoned: Depends on number of alternatives and value of decision; Est. 0.5 to 1.0 sec. for simple 2-3 choice reaction • Manual Dexterity - Highly refined - Automatic feedback and calibration with built-in sensors - Skills = Integrative Patterns • Rate Limits - Essentially single channel (may respond sequentially to multiple channel inputs) - Frequency depends on response and recovery times • Conditioning Factors - Reinforcement - Subconscious control - Specific training - General experience - Knowledge of results	• Vehicle Control in Critical Operations (e.g., rendezvous and dock) • Delicate Manipulations • Application of Graded Force/Time Profiles • Controlling Continually Changing Conditions or Unpredictable events • Fine Control of Instruments • Tracking with Motion Compensation • Emergency Actions • Response to Discrete Signals in Noise • Response to Complex Inputs Requiring Interpretation, Variable Decisions or Incompletely Defined Actuation Patterns.	• Neuromuscular Fatigue • Force Application Limits Relate to Time Patterns - Long duration - Short duration - Bursts • Finite Response Time • Matching of Event Dynamics to Response Time Limits • High Data Rates - Multichannel inputs - Sensory overload - Selective Attention • Environmental Interferences - Distractions may cause failure to detect • Reliability May be Improved by Specific Training

TABLE 13-C

• Decision Making and Information Processing	• Can Operate with Incomplete Information and Make Complex Qualitative Judgments • Large Data Bank - Related data (Training) - Apparently unrelated data (General Experience) • Rapid Interpretation of Unprogrammed Data • Information Analysis Constrained by Sensor Limits • Capability for Inductive and Deductive Reasoning • Capability to Adapt to Changing Situations • Capability to take Advantage of Serendipitous Events • Make Value Judgments - Independently - Cooperatively within crews - Cooperatively with ground science and support teams	• Operational and Command Decisions • Trouble-Shooting • Warning-Signal Evaluation • Corrective Actions in Unprogrammed Situations • Adaptation to New Operational Conditions • Data Evaluation - Selection - Compression - Summarization - Sorting - Selected transmission • Predict Result from Partial Data; Extrapolate • Form Personal Opinion - Relate to other (hypothetical) situations - Relate to other's reactions • Real-Time Readout	• Multiple Channels of Programmed Data with Defined Solutions can be Handled - But Slowly and for Short Periods Only ($\sim$1 hour) • Training and Experience Very Important in Maximizing Application of these Functions • Response/Sensory Overloads - Number of Decisions per Unit Time is Limited. - Short-term storage aids - Control/display compatibility • Possible Motivational Conflicts due to Content of Information - Risks - Payoffs - Priorities

TABLE 14-A

REPRESENTATIVE MAN-MACHINE FUNCTIONAL ALLOCATIONS

Function	Example	Recommended Choice	Reason
		(SENSOR FUNCTIONS)	
Detect signals in high noise level.	Cathode ray tube displays. Communications equipment. Routine radio jamming.	Man	Man can detect masked signals through background noise. Machines are disrupted by interference and noise sources.
Detect low-energy levels. Also detect slight changes in energy.	Weak radar signals. Weak audio signals.	Man	The absolute thresholds of man can approach the random noise of nature, and the slightest changes may be detected.
Scanning to detect signals.	Monitoring target position. Indicator scope.	Man	Man can shift his attention rapidly. Computer programming of this capability is very expensive.
Detect predictable and frequent events, especially over long durations.	Monitoring equipment readiness.	Machine	Man is easily distracted, bored, or fatigued.
Detect unusual or incidental events.	Detect equipment malfunction through smell of smoke.	Man	Machines do not select incidental intelligence.
Out-of-tolerance condition.	Strip Chart to monitor parameters during test	Machine..... Man.......	If small tolerance. If level of discrimination required is large.
Additional or stand-by sensing functions.	Horn alert or warning buzzer	Man	It is usually more economical to use man as a sensor than to provide additional equipment. However, trade-off study may be required in specific instances.
		(GENERAL INFORMATION PROCESSING)	
Process, sort, screen and store large numbers of concrete facts or details.	Ground control of a tactical aircraft squadron requiring aircraft velocity, altitude, rate changes, fuel remaining, distance to target, etc.	Machine	Man's computation ability is weak and relatively inaccurate. He is unable to rapidly store and act upon large amcunts of quantitative data. Machines can be programmed to accomplish these functions.
Use multiple channels and memory areas simultaneously.	Multiplex telephone switchboard	Machine	Man's channel capacity is limited to relatively small information rates. Automated equipment is best at timesharing and handling multiple sources of information.
Use short-term storage and retrieval of large amounts of data.	Airline reservation system.	Machine	Machine can coordinate and keep track of entries from many points. Man must enter information serially, or inductively.
Routine or repetitive functions.	Periodic check of fuel supply.	Machine	Man is typically a poor monitor and is easily distracted, bored or fatigued.

TABLE 14-B

Make routine decisions according to specific rules.	Test an electrical component for conductivity and reject.	Machine	Computers are particularly adept at this function, man gets bored.
Long-term storage and retrieval of meaningful complex material to reach a decision.	Design of a launch pad. Responding to enemy evasive tactics. Decision to attack target.	Man	Man can act selectively on the basis of a large number of possible variables. Man can respond to changing dynamic situation; machines require reprogramming, MAN CAN OPERATE IN THE ABSENCE OF COMPLETE INFORMATION.
Insight, discovery, or problem solving. Unpredictable situations.	Teaching (or learning) new concepts.	Man	Man can make inductive decisions and generalize from few data; machines have no equivalent capacity.
Pattern recognition and interpretation.	Sonar. Wave forms of test oscilloscopes.	Man	Man can recognize and use information redundancy (patterns) of the real world to simplify complex situations.
	(SPECIFIC INFORMATION AND CONTROL APPLICATIONS)		
Perform in isolated and/or monotonous surroundings.	Monitor missile status in a silo.	Machine	Man cannot tolerate long periods without sensory stimulation; otherwise vigilance and performance degenerate.
Perform in noisy and uncomfortable surroundings.	Monitor the temperature of a heat treatment process.	Machine	Machines can perform monitoring and actuating functions regardless of noise or "uncomfortable" surroundings. Man's performance suffers in these situations.
Actuate many things at once (parallel operation).	Transmission of missile alert status to several direction centers.	Machine	Man is very limited in the number of simultaneous responses he can make.
Perform repetitive responses with a uniform output.	Punch rivet holes.	Machine	Machines can perform a completely defined actuation more reliably.
Respond rapidly.	Solenoid valve.	Machine	Man's response time is relatively high (0.2 to 0.3 seconds). Machines can be designed for very rapid response.
Withstand large forces and generate them for prolonged periods.	Booster erection with transporter erector.	Machine	Man can tolerate only relatively low imposed forces and generate relatively low forces for one to three minutes.
Make highly refined and coordinated movement.	Rendezvous and docking of spacecraft.	Man	Machines cannot ordinarily and economically produce the highly refined movements of which humans are capable.
Provide a control mechanism involving prediction, use of stored experience and adaptability to a changing environment.	Command a combat unit.	Man	Man combines into one unit a continuously operating, adaptable, closed-loop control mechanism with wide capacities for resolving time-dependent problems.
Respond rapidly to unpredictable events.	Safely land an aircraft after a mid-air collision.	Man	Man can compensate for the unexpected; computer programs cannot.

Crew Selection and Skill Composition:

Efforts should be made to minimize engineering constraints on crew selection criteria so that a wider range of individuals can potentially travel in space. This will allow primary selection of the best qualified individuals for specialized scientific tasks or extreme operational demands.

Table 15 shows how typical functional compositions of small isolated groups working under demanding conditions cover their operational needs. Composition of flight crews during prolonged space missions must include a Mission Commander (astronaut-pilot), a Flight Surgeon (astronaut-physician), a Scientific Coordinator (astronaut-scientist) plus a number of scientists, technicians or co-pilots. Compatible skill mixes and cross-training of individual crew members are necessary for multidisciplinary activities with limited crew sizes as shown in Table 16 (Ref. 42). Crew sizes of 4 or larger are desirable, especially for missions involving long-term independent operations.

Leadership:

Authority structure should be quasi-military; although for maximum effectiveness, the Mission Commander's formal authority must be accompanied by genuine respect from other crew members.

The Scientific Coordinator organizes, sets up priorities and (if needed) redefines research objectives. He also specifies the operational profiles most compatible with optimizing scientific results. The Mission Commander is responsible for operating the vehicle and for assuring crew safety. Final approval for operational demands imposed by scientific requirements rests with the Mission Commander, inasmuch as assurance of crew safety takes precedence over all other considerations.

TABLE 15

TYPICAL OCCUPATIONAL COMPOSITION OF SMALL GROUPS WORKING IN RELATIVE ISOLATION UNDER DEMANDING CONDITIONS*

Administrator (executive officer)

Radio communicator(s)

Station keeping or equipment operator(s)

Electric/electronic maintenance personnel

Mechanical maintenance personnel

Cook(s)

Medical doctor(s)

Where crew size is less than the minimum number (seven) of occupational categories above (e.g., Mercury, Gemini and Apollo) then multidisciplinary functions are assigned to the crew and/or equipment reliability is assured.

*e.g., Antarctic stations, remote defense bases, combat submarines, surface ships, remote power generating stations.

TABLE 16

SPACE STATION CREW AND SKILL REQUIREMENTS

SKILL / PROGRAM AREA	BASIC SKILLS						SPECIALIST SKILLS								
	ELECTRONICS TECHNICIAN	PHOTOGRAPHER/ OPTICAL TECHNICIAN	ELECTRICAL/MECHANICAL TECHNICIAN	ELECTRONICS ENGINEER	MECHANICAL ENGINEER	MEDICAL DOCTOR	AGRICULTURIST	ASTRONOMER	BIOLOGIST	CHEMICAL ENGINEER	GEOLOGIST	MEDICAL TECHNICIAN	METEOROLOGIST	OCEANOGRAPHER	PHYSICIST/PHYSICAL SCIENTIST
ASTRONOMY	√	√		√				√							
EARTH RESOURCES	√	√					√				√			√	
METEOROLOGY	√	√											√		
BIOLOGY									√						
LONG-TERM FLIGHT			√	√	√	√				√		√			
RESEARCH AND DEVELOPMENT	√		√	√	√										√
ORBITAL OPERATIONS	√	√	√												

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L. F. Dietlein M.D.

L. F. Dietlein

B. A. Gropper

B. A. Gropper

W. E. Hull

W. E. Hull

A. N. Kontaratos

for R. S. Mach

R. E. McGaughy

R. E. McGaughy

1011-LFD
BAG ab
WEH jd
ANK ss
RSM dy
REM

Attachments
References
Appendices A-C

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APPENDIX A

THE ORGANISM-ENVIRONMENT SYSTEM

THE ORGANISM-ENVIRONMENT SYSTEM

MONITORING THE SYSTEM'S STATE

The living organism interacts continuously with the external environment which supports its existence. From the environment the organism draws oxygen, absorbs energy, extracts nutrients, seeks protection, and, to it, returns wastes and heat.

Changes in the environment affect the organism directly and elicit preservation reactions. These reactions assure survival by either facilitating acclimatization to the new conditions or allowing the organism to escape from harmful situations. If neither alternative can be realized, the organism faces irreversible damage and possible death.

To protect themselves against a threatening change, higher forms of life monitor continually their physical environment and their own physiological functioning as affected by external conditions. Thus, a perpetual stream of almost inexhaustible variety of informational signals is gathered and transmitted to evaluation centers via sensory pathways. There, the information is analyzed and appropriate responses are determined allowing the organism to cope effectively with developing events, circumstances or conditions. Input signals to evaluation centers are called stimuli. They are transmitted in the form of nerve impulses generated by sensory cells specialized to react to physical, chemical or mechanical factors.

A classification system for stimuli can be conceived as involving three separate dimensions: origin, inherent interpretability and biological significance.

In terms of origin, stimuli can be internal or external. Internal stimuli originate from within the body and reflect conditions of general well-being. External stimuli originate from outside the body and reflect objective environmental realities.

With respect to their inherent interpretability, stimuli can be symbolic or non-symbolic. Symbolic stimuli are those whose meaning is not inherent in the situation which gives rise to the stimulus but is acquired by learning from experience or social disclosure. Examples include all human languages in either written or spoken forms. Words heard or read are external symbolic stimuli*. Thoughts and imagery are internal symbolic stimuli. Alternatively, non-symbolic stimuli are those whose significance is inherent in the situation. Examples include hunger, on the internal side and physical discomfort, on the external side.

Lastly, with respect to their biological significance, stimuli can be positive (inherently beneficial or subjectively gratifying), negative (inherently harmful or subjectively unpleasant) or indifferent (inherently neutral, but potentially capable of eliciting a response).

INTERNALLY ADAPTIVE RESPONSES

Direct exchange of energy and materials between the constituent cells of an organism and the world outside is not always possible. Complex organisms consist of organized cell aggregates, the resulting bulk of which prevents most individual cells from coming into direct contact with the external environment. To provide their cells with life sustaining ingredients all higher organisms have developed an internal environment with which most of their constituent cells interact directly (exceptions include, for example, the epidermal cells which are dead anyway). Specialized organs and tissues have also developed to assume the role of an intermediary transport system linking together the internal and external environments. The respiratory and the digestive systems, for example, supply the bloodstream with oxygen and nutrients, respectively. The bloodstream in turn distributes these ingredients to all cells throughout the body.

From the cellular standpoint the interstitial fluid and the blood plasma are the controlling environment. Cells carry out continuous biochemical exchanges with the interstitial fluid which, in turn, is in open exchange with the blood plasma. Collectively these two media constitute the "internal environment" of the body.

The physical properties (e.g.,) osmotic pressure, arterial pressure, viscosity, temperature) and chemical characteristics (e.g., pH, concentration of sugar and various ions) of the internal environment are normally maintained within prescribed limits. (Ref. 1 and 2) Variations outside

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*The capacity to learn a symbolic language is genetically bestowed and, for man, has made cumulative experience and cultural transmission possible. Language is also one of the channels through which the cultural environment exerts its formative influence on human personality.

these limits can affect the well-being of body cells and lead to degradation of mental and physical performance. For example, a deviation of plasma pH from the normal value of 7.4 by ± 6%, a change of serum calcium from 10 mg/ml by ± 50%, a change of blood sugar from 1 mg/ml by ± 70%, or a change of body temperature from 98.6°F by + 10% or -20%, can lead to loss of consciousness and death (Ref. 3).

The sensitivity of the organism to change requires that regulatory mechanisms developed by evolution minimize the propagation of external disturbances to the internal environment. These mechanisms allow the organism to accomodate initially and acclimatize subsequently to an altered set of external conditions. One sees an example of this in mountain climbers who first react to the low oxygen environment by breathing faster and deeper as the compensatory mechanisms increase the respiratory effort to bring more air into the lungs. This initial accommodative phase is followed by a more permanent solution, acclimatization, if exposure is sufficiently prolonged or stressful. The blood forming organs are then driven to produce additional red cells which increase the oxygen carrying capacity of the bloodstream. Thereafter the accommodative process is no longer needed and subsides or disappears.

The compensatory capabilities of the various regulatory mechanisms is not rigidly fixed. Within limits, it expands as the operational range of the various effector organs or systems widens with increasing intensity and frequency of adaptive response. For example, heavy workloads enhance overall physiological tolerance to exhaustion and develop further the musculoskeletal and cardiovascular systems.

By adjusting the operating characteristics of appropriate regulatory mechanisms, the body manages to meet external demands without compromising internal constraints. What changes during this process is the physiological state* of the organism which stabilizes to a new plateau as soon as a balance between external action and internal reaction is achieved. This condition of physiological steady state reached, when the organism attains equilibrium with its environment, is called "homostasis".

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*The physiological state of an organism at any one instant is defined as the set of conditions describing both the physicochemical properties of the internal environment and the operating characteristics of the regulatory mechanisms at that instant.

Change in physiologic state occurs for other reasons besides fluctuations in the physical environment. Muscular effort, pathologic factors (e.g., disease, injury, etc.) and emotional conditions can also selectively activate regulatory mechanisms and, hence, trigger changes in the internal environment. The purpose of the resulting functional alterations is to satisfy new demands imposed by developed conditions or to increase body readiness to cope with anticipated events.

With regard to accepted states of well-being, one finds that homeostatic parameters are not numerically identical for all individuals at a given time or invariant for the same individual as a function of time. Traditionally, the definition of normality allows for such physiologic variabilities without regard to their possible cause. One, thus, refers to an accepted "normal range" which is set by the numerical distribution of the measured parameters in a reference population. Individual variability within this "normal range" is attributable to predisposing factors. These are of two types, internal (genetic unfolding, physiologic state, learned behavior) and external (medication, diet, other concurrent external events or circumstances). Variations beyond the "normal range" are considered pathologic justifying the need for clinical diagnosis.

The ability of organisms to adapt to physical changes in the external environment extends to both the spatial and temporal domains. Homeostatic parameters undergo rhythmic variations in amplitude (biorhythms) which have been shown to possess three important characteristics. First, they are more than just mere fluctuations around hemeostatic means; they are cyclic alternations of the normal values themselves. Secondly, some physiologic rhythms are in definite synchrony with external factors. For example, the diurnal variation in daylight is known to entrain many metabolic and neuro-humoral functions. Thirdly, fixed phase relationships are normally maintained between rhythms displayed by different physiological functions. This relationship, however, does not necessarily mean that rhythms of similar periods coincide in phase. For example, excretion of urinary potassium, sodium and magnesium exhibits a persistent diurnal rhythms. In healthy subjects peak potassium excretion follows peak sodium excretion by about 5 hours and precedes peak magnesium excretion by about 12 hours (Ref. 4).

Biorhythms are largely determined by heredity and differ with the species. Some are the result of evolutionary adaptation to cyclic changes in the environment which have continued since the beginning of time. The most obvious physical phenomenon exhibiting natural periodicity is the relative motion of the sun and moon resulting in day and night, high and low tide and the four seasons of the year. These variations, in turn, affect such external factors as light, humidity and temperature. Less obvious phenomena of variable intensity which may also exert a physiological influence in clude geomagnetic fluctuations and cosmic radiation (Ref. 5). For example, preliminary results from studies of a specific type of mental disorder indicate that intense surges of aggression correlate with geomagnetic disturbances caused by solar flare activity (Ref. 4).

Despite their genetic character, biorhythms are not immutably set. Within certain limits they can slowly shift phases to compensate for corresponding changes in the entraining stimulus. For example, it takes from several days to three weeks for man to adjust metabolic and neuro-humoral functions to a new daily rhythm following quick transition from one time zone to another of opposite phase. Adjustment of separate functions to the new time schedule occurs with differential rapidity. Thus, part of the distress some world travellers experience may stem from internal desynchronization caused by differences in the rate of adaptation of physiological systems to a rapid change of time zones (Ref. 4).

Biorhythms can adapt to periods shorter or longer than 24 hours but the range of adaptation is narrow. If under artificial conditions the period of the entraining stimulus (e.g., daylight) is set too fast, too slow or is entirely missing, then biorhythms cease to be synchronized with the environment and become "free-running" with periods usually varying between 19 and 29 hours (Ref. 5). Under such circumstances the amplitudes of these rhythms may also change.

Ordinarily, physiological functions are regulated so that their diurnal rhythms maintain fixed phase relationships. Free-running conditions in exotic environments, or aritifical daily schedules in ordinary environments, can disrupt normal temporal couplings (Ref. 6 and 7). For example, even after working nights shift for a long period of time, many functions of the body retain their original day/night phase positions while others, like sleep, undergo a complete phase reversal. Such desynchronization of diurnal rhythms may lead to physical or mental sickness. The reason for this is that individual biorhythms are phased relative to each other in such a way as to assure orderly cooperation of body systems and re-enforcement of component processes (Ref. 8). Disruption of temporal coordination among the multitudinous physiological cycles can set one rhythm into a phase relationship with another in such a manner that would generate a periodic beat manifested clinically as a recurrent symptom. Diseases are known whose symptom occur at intervals of several days, weeks, or even longer periods (Ref. 9). A typical example is epilepsy. Clearly studies of internal phase relationships among physiological rhythms can provide diagnostic cues to some illness and allow more accurate forecasting of impending disease symptoms.

According to one school of thought(Ref. 10 and 11), bioregulation of a complex biological system such as the human body is achieved by modifying the output of a large number of physical and chemical oscillators operating continuously within the system. These oscillators can be viewed as physiologic mechanisms eliciting rhythmic fluctuations of physical parameters or constitutent concentrations. In man, about 40 fluctuations at the subcellular, cellular and systemic levels are known to exhibit rhythmicity with periods ranging from milli-seconds to months. For example, neural frequencies are in the range of 5 to 50 cps, the respiration rate is about 16 cycles per minute, eating cycles are 2 to 4 per day, circadian rhythms are 1 cycle per day*, sex drives are 1 cycle per few days, ovulation in the female is about 1 cycle per 28 days, and many others.

The standard operating scheme of a biologic system can then be regarded as a dynamic process in which various cross-coupled oscillators act as pacers affected by specific electrical and chemical signals which retard or advance their frequency and decrease or increase their amplitude according to need. Homeostasis is adjusted by shifting the operating level of these biologic oscillators to regulate physiologic variables in space (anatomical site) and time. For example, the level of sugar concentration in the blood exhibits oscillatory fluctuations, the mean amplitude of which is partially controlled by the rhythmic interaction of two hormones (insulin and glucagon) affecting antagonistically the process of glycogenolysis.

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*These include: sleep and waking, body temperature, blood pressure, oxygen utilization (respiration), pulse rate, secretion of many hormones, urine formation, blood count, cell division, protein utilization (amino acid levels), blood glucose level, excretion of urinary electrolytes and others.

EXTERNALLY ADAPTIVE RESPONSES

Behavior is the observable way an organism reacts to a stimulus or a combination of stimuli. Classification of behavior may be made in terms of direction, quality and modes of acquisition and expression.

Behavior may be directed inwards affecting homeostatic conditions, outwards modifying suitably the organism-environment interfaces, or both ways. For example, perception of threat (external negative stimulus) can trigger such internal affects as pounding of the heart, tendency to overbreathe and unpleasant intestinal upsets. Conversely, outward directed behavior is only expressible in terms of neuromuscular action.

The quality of the behavior of an organism displays is determined by subjective cost-reward considerations involving the projection of probable consequences that alternative modes of action may produce. Based on the outcome of such considerations, approach, avoidance or indifferent behavior is initiated. Absence, denial or loss of positive stimuli and/or exposure to negative stimuli constitute the costs in this trade-off analysis. Alternatively, exposure to positive stimuli and/or removal of negative stimuli constitute the rewards. The intensity of behavior in seeking positive stimuli and/or avoiding negative stimuli defines the level of motivation. Motivational values vary for different people, but, in general, highest values* are assigned to such aspects as interest in work, sense of pioneering, fame, career benefits, money, pride in unique achievements. Examples of the power of motivation can be seen in the behavior of early explorers some of whom endangered and even lost their lives for what they believed were worthy causes.

Acquisition of behavorial patterns may be inborn or learned. Inborn patterns (also known as unconditional reflexes) arise from genetic unfolding. They tend to be manifested alike in all members of a species and to emerge fully formed without previous training the very first time the triggering stimulus is applied. Examples are the sucking, swallowing, breathing, crying or grasping behavior of the newborn infant and the pupil reaction to light or the muscular contraction in pain present to both infants and adults alike.

Instincts are also forms of inborn behavior only more complex than simple unconditional reflexes (Ref. 12). They involve intricate patterns of preprogrammed activities reaching astonishing perfection as evidenced, for example, by the nest building capability of birds, the pecking of newborn chicks at appropriate food-like targets or the navigational capability of newly hatched turtles.

*Besides the obviously important needs of breathing, eating, resting, etc.

Inborn behavior consists essentially of a repertoire of basic activities highly deterministic, relatively invariant and rigidly cued. Its purpose is to help assure survival by means of a limited number of fundamentally significant reactions, since it is virtually impossible to safeguard the organism by genetically coding instructions against all combinations of conceivable undesirable situations. Thus, although normally beneficial, inborn behavior can become hazardous in itself if it is displayed under no longer appropriate conditions. This fundamental limitation of inborn responses is normally minimized through learned behavior.

Learned behavior can be of two kinds: operantly and classically conditioned. Operantly conditioned behavior is neither rigidly preprogrammed nor rigidly cued. If the input signals to the CNS represent a situation that cannot be handled by inborn behavior then a conscious choice of the seemingly best response from a range of identifiable alternatives, is made. If the same situation arises again, the brain will recall the previous experience and will be guided in making a response by the cost-reward consequences of the actions it has generated previously. In this manner undesirable modes of behavior are normally extinguished and appropriate ones perfected. Furthermore, as the individual becomes gradually more proficient, his acquired response skills submerge more and more into the subconscious until eventually they become completely automatic. Thereafter, learned reactions are expressed in a manner similar to that displayed by inborn ones. This process eliminates the necessity for concentrating on repetitive tasks, once mastered, and allows the individual to work towards achieving his full potential (self-actualization) by attending to progressively higher order goals in his subjective priority structure. On the other hand, as one's responses become increasingly better with practice, the need for feed-back information on the consequences one's actions have generated, diminishes accordingly. This tendency for behavior to minimize feed-back can in some instances restrict, or even prevent, perfection since errors in performance can go undetected and, therefore, remain uncorrected.

The capacity to control one's destiny either by selecting a subjectively best course of action among available alternatives, or by choosing the environment which satisfies his needs best, can be defined as individual freedom. Note that knowledge of available alternatives merely widens the range of choice, whereas knowledge of potential consequences tends to eliminate alternatives and narrow down the choice. In view of this it is not unreasonable to relate intelligence to selection. What is remarkable in a genius is his ability (through a better than average comprehension of relations) to define options and retain from the totality of existing possibilities those selected few that can serve his goals best.

Unlike the process of trial and error learning, which is relatively independent of inborn behavior, classically conditioned learning builds upon inborn responses (unconditioned reflexes). Simple or composite external stimuli which have not been preprogrammed to act as cues for unconditioned reflexes can, under certain circumstances, acquire the capability of evoke inborn behavioral responses (Ref. 13). This occurs when they are repeatedly applied in combination with a stimulus* which normally elicits an unconditioned reflex. In time the response previously evoked only by the unconditioned stimulus is transferred to the previously indifferent stimulus. For example, the ringing of an alarm bell can trigger evasive action even when the hazard is not obvious. This situation will persist as long as the new meaning acquired by the previously indifferent stimulus (now called a conditioned stimulus) is reinforced through concommitant application of the unconditioned stimulus. If, over a given time the conditioned stimulus is presented without the accompaniment of the unconditioned stimulus, then the conditioned stimulus will lose progressively its acquired special meaning and in turn its response effectiveness. Through classically conditioned behavior normally indifferent stimuli can be used as cues if they precede events of obvious concern to the organism.

As mentioned earlier, the expression of behavior may be automatic or voluntary. Automatic behavior normally includes all inborn reactions and those learned responses which have been practiced to almost perfection. However, both types of responses are subjected to some forms of voluntary override. A typical example of this is seen in breathing. One usually breathes without necessarily becoming aware of, or consciously controlling, the respiratory process. However, one can modify at will both the depth and rate of respiration.

Voluntary behavior can be conceived as occurring in two phases. In the first phase, an impinging stimulus elicits a motivational state which primes the organism to take adaptive action. Such motivational states are called "drives". In the second phase, adaptive action is initiated and directed towards satisfying the existing drive. Usually, the predominant drive among a host of often competitive ones determines the overall mode of behavior (Ref. 14).

Two types of drives are distinguishable: homeostatic and non-homeostatic (Ref. 15). Homeostatic drives arise as a direct consequence of internal non-symbolic stimuli (deviations in selected physical parameters or imbalances in constituent concentrations) which activate specific brain centers. These

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*Such a stimulus is called an unconditioned stimulus.

drives are expressed as attempts to satisfy physiological needs (hunger, thirst, sleepiness, fatigue, mating, etc.) and are satiated when, as a result of the action taken by the organism, the internal variables which initially aroused the drive return to subthreshold levels. For example, a reduction in the blood sugar level potentiates the drive of hunger, prompting the organism to search for food within that part of the environment which is accessible to its reach.

Non-homeostatic drives arise as a result of internal symbolic, external symbolic or external non-symbolic stimuli. For example, variations in physical environment parameters are translated into sensory messages which, when decoded by the CNS, elicit distinct sensations (pain, noise, heat, pressure etc.) or emotions (fear, anger, pride, unhappiness, etc.). It appears that emotions are a basic part of the framework within which an individual apprehends his environment and responds to it (Ref. 16). The reason for this is that through emotions a gradual emergence of self-image and self-awareness evolves relating subjective individual experiences with objects and events in space and time.

All sensory stimuli that evoke distinct sensations or emotions are potentially capable of eliciting non-homeostatic drives. The effectiveness of the stimulus input in eliciting these drives, however, it almost totally determined by learning (Ref. 15). One must have had a similar experience on at least one, usually on several, occasions in order to develop appropriate models by which to interpret the significance of the incoming sensory signals.

Non-homeostatic drives persist until, by some voluntary action, the individual has satisfied the drive, has suitably modified the causative stimulus or has removed himself from the environment. If none of these alternatives is possible, the original drive (assuming it is not pathogenic) will persist until eventually other drives, either homeostatic or non-homeostatic, develop and predominate. These new drives can be activated or strengthened either as a direct consequence of the persisting unsatisfied original one or because different competing or stronger needs have developed meanwhile.

A classification system of some of the most important drives is provided in Table I. It is of interest to note that in this table, drive categories (A) and (B) support the achievement of an intrinsic purpose set by nature itself. Alternatively, category (C) supports the achievement of goals set by man either on an individual or collective basis. It is an interesting thought to propose that harmony between man and his world is achieved when the three drive categories become synergistic and mutually supportive.

TABLE I

DRIVES GOVERNING ORGANISM-ENVIRONMENT RELATIONS

A. SELF-PRESERVATION

Breathing
Food and water seeking
Eating and drinking
Excreting
Shelter seeking (or building)
Threat escaping (or eliminating)
Resting and sleeping
Exploring and expanding territories

B. SPECIES CONSERVATION

Competing
Mating
Nursing
Caring
Sharing
Protecting

C. SELF-ACTUALIZATION

Consciously defining purpose
Elaborating behavior to achieve purpose

In addition to physiological periodicities, living beings also exhibit behavioral rhythms. Thus, man's ability to perform complicated manual tasks or intricate mental activities does not remain constant throughout the 24-hour cycle. Obviously, the rest and activity cycle is particularly significant serving to synchronize many other rhythms to the daily routine of waking and sleeping. For example, sensory acuity, perceptual discrimination, memory formation, and reaction time are some of the processes known to vary as a function of clock time (Ref. 4). For a normal person who goes to sleep regularly at about 11 p.m., sensory acuity appears to reach a peak at about 3 a.m. which is the time of lowest steroid levels. After 3 a.m. there is a sudden drop in acuity as steriod levels begin to rise. While steroid levels decline during the course of the day, acuity increases. Around 5 to 7 p.m. another peak in sensory acurity is reached. Interestingly enough, sensory acuity and perceptual discrimination are in phase opposition so that when one reaches zenith the other reaches nadir (Ref. 4).

Judged on the basis of overall efficiency, however, peak performance coincides with the time of peak body temperature, which is reached around middle afternoon or early evening (Ref. 4). Favorite hours of the day are found to coincide with the higher part of the temperature cycle reached in about 3 hours following preferred waking time. Work-rest schedules can thus be tailored to individual preferences to assure maximum performance.

Recent studies further suggest that subjective estimates of time intervals are modulated through a metabolic-chemical pacemaker system in the brain which can be influenced by administration of drugs that alter the background state of consciousness, and by variations in body temperature (Ref. 4). Assuming that the state of consciousness is not interferred with by drugs, estimation of elapsed intervals tend to be shorter than actual clock time when body temperature is high, and vice versa. Contraction of subjective time is accompanied by an apparent expansion of personal space. Conversely, expansion of subjective time tends to accompany contraction of personal space.

Emotional rhythms (e.g., mood fluctuations) are also known to occur in periods of several days or longer but usually pass unnoticed in the normal person. They appear to be synchonized with slight exaggerations or imbalances in normal glandular cycles.

REGULATION AND CONTROL OF BIOLOGIC FUNCTIONS

GOVERNING PRINCIPLES

According to information theory, the capacity of a system to act as a regulator depends upon the same system's capacity to act as a channel of communication. This suggests that the extent to which external disturbances reach and affect the internal environment is determined by the amount of relevant information received at the regulatory centers. Obviously, higher quality information results in more precise regulation and it is for this reason that the evolutionary process has provided higher organisms with specialized physiochemical receptors for internal monitoring and diversified sensors for external cueing. Additionally, since the quality of the informational input must be preserved during both transmission and evaluation, signals are routed through specific pathways to specific processing sites each of which is specialized to handle a particular type of information best.

The ability of the living organism to retain its state of equilibrium with the changing external world and at the same time control its internal environment within prescribed limits, suggests that the organism handles concurrently an enormous number of variables. It follows that the information generated and transmitted back and forth between sensors, processors and effectors must be truly colossal on all levels.

Like any other communication devise the integrative centers of the central nervous system have a finite informational handling capacity in terms of both multitude of signals and data density per signal (Ref. 17 and 18). Consequently, incoming information must be hierarchically screened and reduced long before it reaches these higher centers. Studies confirm that the competition for the interest of the integrative centers is high and priority is given for that moment in time only to those signals that are most significant biologically (Ref. 19 and 20). Internal or external stimuli of either positive or negative values are singled out and their transmission to higher centers is facilitated (Ref. 17). Conversely, the transmission of indifferent stimuli is attenuated and effectively blocked (Ref. 17). This selective attenuation is accomplished as far away from central processors as possible. The cost of such defense against central overloading is the amount of significant information that may be sacrificed in order to attentuate indifferent signals.

At this point, it is legitimate to ask through what process the content of the incoming information is discriminated for appropriate selection.

It has been established that the regulation of biological processes is organized at various levels. Higher and lower instances of such organization have been documented (Ref. 5). At higher levels processes are synergistically coordinated to fulfill a specific functional purpose. Lower levels possess autonomous traits and, within limits, regulate individual component activities. There is also evidence to suggest that excitation of higher levels does not occur as a direct result of the original information (Ref. 21 and 22). Rather, it is invoked by discrepancy signals which develop when the incoming information fails to match predictions made by internal models. Sensory signals specify the initial conditions of the system and it is on this basis that internal models begin cycles of simulation on an accelerated time scale to generate predictions regarding the system's future. Depending on the particular type of function that these models represent, they are either genetically determined or established by learning. Through them the body keeps a fairly accurate and complete image of itself and of the external environment. Apparently this image is continuously updated at a high frequency rate, possibly near the neural frequency of about lo cps (Ref. 11). Thus, through information gathering, transmission and processing the well-being of the individual is assured and the stability of the organism-environment system is maintained.

The complexity of highly evolved organisms in terms of variables that must be coordinated suggests that iterative regulation of all body functions as an ensemble is time-wise prohibitive (Ref. 23). Two alternative processes are used to accomplish the same feat. One requires that specific sequences of events stimulate specific sets of matched reactions. For this to be possible preprogrammed instructions must exist which, like a vast vocabulary, can be released in endless combinations, each combination appropriate for coping with a particular event. Such preprogrammed instructions must be component parts of the available internal models and, like the latter, must be either inherited or learned. In this context learning is tantamount to model formation or model update.

The other alternative process requires that beneficial effects accruing from a variety of component responses each occuring independently of all others, be conserved and accumulated. For this to be possible the living organism must be able to selectively couple and decouple various functional systems in order to re-organize its activities according to need (Ref. 23).

Once this process succeeds in coping with a particular situation, then both the specification of the problem resolved and the attained solution are used to update the model bank. Investigations confirm that models of increasing complexity are stored at, and put to use by, progressively more sophisticated regulatory mechanisms.

In this scheme of things biorhythms play an important biological role by permitting smoothness and continuity in the functioning of an organism through rigid timing of interdependent component processes. Phase dissonance among physiologic rhythms has now been identified as a cause of sickness (Ref. 4). Interestingly, however, the hypothesis of a master clock in the brain is not supported by existing evidence. In vitro tissues, isolated adrenals and even single cells exhibit persistent rhythmicities, a fact which confirms that time sensing is an inherent characteristics of all life units on earth.

Traditionally, the functions of an organism are grouped into two categories, internally and externally adaptive. Internally adaptive functions are concerned with the maintenance of optimal conditions within the internal environment of the body primarily for the purpose of restitution of energy in the cellular components of the organ systems. They include blood formulation, blood circulation, blood coagulation, respiration, digestion, excretion, thermoregulation, general metabolism, reproduction and immunity.

Alternatively, externally adaptive functions allow the individual to (a) establish contact with the outside world through his senses; (b) perceive and evaluate situations through higher mental processes; and (c) adapt his behavior to internal or external needs through neuromuscular actions.

INTERNALLY ADAPTIVE FUNCTIONS

Considering the biologic structures in relation to their function three basic, although highly overlapping, levels of organization are distinguishable. These are the cells, the organs and the various regulating systems (Ref. 20).

Every act of function performed by any one living organism as an entity is, in the final analysis, realized through cells. Consequently, preservation of cellular well-being is basic to existence and the various internal organs were evolved to subserve this very purpose.

In general, each internally adaptive function can be regarded as being either in a stationary (stable) or in a transient (unstable) state. Stationary (stable) are homeostatic, meaning that the time average of statistical variations in internal parameters remains constant at the normal values.

Transient states develop when homeostasis is lost and a new stationary plateau is being sought. Not all regulatory systems are necessarily involved in search of homeostasis. Those that become involved, however, respond in varying degrees and with varying rapidity.

As mentioned earlier the regulatory systems are hierachically organized into lower and higher levels (Ref. 5, 19 and 20). Under normal circumstances lower levels are self-monitored and self-regulated. Higher control levels supervise this lower level independency and intervene to restrict it if unforeseen situations develop resulting in inadequate of antagonistic lower level efforts. Transfer of control from a lower to a higher level occurs when discrepancy signals between what actually is and what ought to be, in terms of internal conditions, reach an established threshold amplitude (Ref. 20). Such discrepancy signals can propagate progressively from the lowest to the higest control level if all intermediate ones fail to cope satisfactorily with an undesirable situation. Internally adaptive responses to an internal or external stimulus are, in turn, determined both qualitatively and quantitatively by the nature and intensity of the acting stimulus and the physiologic state of the organism at the time the stimulus was applied.

In man, four basic regulatory levels are found (Ref. 19). The first level is the internal environment of the body. Physical or chemical changes in this environment affect directly many sensitive internal organs (e.g. kidneys, liver, lungs, heart, etc.) which, in themselves, possess the capability to respond correctively by shifting their operating characteristics to more appropriate levels. For example, physical activity affects the internal environment which in turn triggers alterations in myocardium metabolism, in the flow of blood to cardiac muscles, in cardiac contractibility and other functions. If these measures prove insufficient, then conditions will arise necessitating active intervention of higher control mechanisms.

The second regulatory level is the endocrine system. This releases, primarily into the bloodstream, minute quantities of highly active substances (hormones) which selectively enhance or depress the activities of specific target cells or organs. The determinant of response specificity is not the hormone itself but the sensitivity of the target cells or organs to a particular hormone (Ref. 24). Normally, endocrine secretions exhibit a regular rise and fall that adheres to a diurnal cycle (Ref. 4).

Much evidence exists to suggest that the endocrine system is controlled through intricate neuro-chemical feedback mechanisms. For example, during emergencies the body mobilizes the pituitary and adrenal glands to act as part of the main defenses. Information concerning the emergency, be it internal or external, causes the brain (presumably the hypothalamus) to secrete the "corticotropin-releasing factor", a chemical designed to stimulate the pituitary to secrete the hormone ACTH. This hormone, in turn, stimulates the adrenal glands to release a class of stress hormones known as corticosteroids. The amount of corticosteroids circulating into the bloodstream is continually monitored by specific receptor sites in the brain to assure that it is maintained at the situationally appropriate level. If the amount of corticosteroids in the blood deviates from the prescribed level, then these receptors activate neural mechanisms which modify correctively the release of the regulating hormone ACTH. In many respects the pituitary acts as the "master hormonal gland", controlling the activities of most others.

It is also well established that hormones are somehow connected with emotional reactivity and learning, but the precise nature of this interaction is presently unknown (Ref. 15). A possible hypothesis is that through the hormone-reception sites in the brain, imbalances or exaggerations in glandular secretions, either naturally or artificially induced, exercise an influence upon central control processes including those responsible for behavior. Conversely, psychological stressors always trigger the release of pituitary-adrenal hormones.

The third regulatory level is the autonomic nervous system. Nerve endings (receptors) are strategically located throughout the body to sense changes in both the internal environment and the operating characteristics of the various regulatory organs. Through these receptors information regarding internal conditions is received at the autonomic centers. Appropriate solutions to problems are retrieved from model banks if available there, or are developed in their entirety for the first time if not available, and commands to effector organs, including endocrine glands, are issued. Several regulatory sub-levels are distinguishable within the autonomic system. For example, lower sub-levels regulate the activities of individual organs. Higher sub-levels coordinate the activities of several organs entrusted collectively with the control of a single systemic function (e.g. breathing, blood circulation, etc.). Still higher sub-levels integrate the various systemic functions to satisfy the overall physiological requirements of the entire organism.

Anatomically and functionally, the autonomic nervous system is distinguishable into the sympathetic and parasympathetic divisions. These two divisions have antagonistic effects on the organs they control. One acts to inhibit or reduce activity, the other to stimulate or increase it.

Autonomic regulation differs from hormonal regulation as to its speed of response, duration of control and site of action. In general, autonomic effects are more rapid, less lasting and more spatially restricted than the hormonal ones. For example, vasoconstriction may result from either nerve impulses or hormones acting on blood vessel walls. If nerve impules cause the response, then the constriction occurs almost instantaneously, involves specific vessels and lasts for as long as the impulses continue. In contrast, if a hormonal discharge causes the response, then the contriction is delayed, since the hormone must first get a chance to circulate throughout the body before reaching its targets, is widespread affecting most body vessels, and is long lasting.

The fourth regulatory level is the central nervous system. It responds to informational signals regarding important changes in both the internal and external environments by integrating the activities of the autonomic, endocrine and muscular systems. These signals are received neurally, chemically and even hydraulically (through blood transport) and include inputs from both the special senses and the internal receptors. Through this system the ultimate balance between momentary external needs and internal demands is achieved. If in the process conflicting requirements arise, these are resolved on an established priority basis.

The central nervous system performs two types of regulatory functions (Ref. 24). One, as mentioned above, is extrinsic and concerns the regulation of subordinate organ systems. The other is intrinsic and concerns its own regulation achieved through the control of neural activity states. Important to this second function is the question of self-awareness or consciousness involved in voluntary behavior. Central nervous system activities generate brain-wave patterns which exhibit diurnal rhythms and which can be measured electrically to provide a crude indication of the background state of consciousness (Ref. 4). The intrinsic function of the central nervous system is discussed in the next section.

The regulation of internally adaptive functions is achieved partly through preprogrammed instructions (genetically endowed) and partly through learning. Basic life sustaining elemental functions, such as breathing, swallowing, digesting, excreting, blood forming, blood circulating and others, are preprogrammed. These, as the organism matures, are intertwined with and overlaid by learned regulation. For example, in nonrecurrent diseases the body learns to manipulate its defenses suitably in order to effectively block certain types of biologic aggression. Learning to control voluntarily internal adaptive functions is also possible.

Traditionally, voluntary musculoskeletal responses and higher mental processes (externally adaptive behavior) have been considered more finely differentiated than both emotional reactions and the presumably involuntary autonomic and glandular discharges (internally adaptive behavior). Similarly, a distinction has been made between classically conditioned learning, thought to be involuntary, and operantly conditioned learning, believed to be responsible for voluntary behavior. Recent experiments (Ref. 25 and 26) have convincingly demonstrated, however, that homestatic performance, routinely regulated by the autonomic nervous system, can be modified voluntarily. Modifications in pulse rate, blood pressure, local blood flow, galvanic skin response, skin temperature, resting muscle tone and brain wave rhythms have been reported.

The knowledge that mind and body interact is not new. The healing ability of placebos (medically inert pills), the relief provided by make-believe surgery, and the control of certain physiological functions achieved through hypnosis have all demonstrated the powerful effects of suggestion. For example, to some people the very idea that plant pollen may be present in the air they breathe may elicit the full complex of hay fever symptoms. The novel element introduced here by the aforementioned studies is that learning to control internally adaptive functions is also achievable through operant (or trial-and-error) conditioning formerly believed limited to the somatic activities only. This finding suggests that voluntary intervention in autonomic functions can become specific, reflexive and behaviorally dominant if the evoked responses result in situations that tend to reinforce learning. It is thus possible to attribute certain individual and cultural differences in phsiological performance to psychosomatic effects resulting from such conditioning.

EXTERNALLY ADAPTIVE FUNCTIONS

Behavior displayed in response to a stimulus is determined and coordinated by three general types of nerve cells (neurons). Receptor neurons receive information from sensory organs and transmit it to specialized projection areas in the central nervous system (CNS) for evaluation. All connections between receptor neurons and sensory cells are highly specific with genetically determined spatial relations (Ref. 24). Effector neurons connect to skeletal muscles or internal organs and transmit CNS directives to either. Control neurons in the CNS encode and mediate information between receptor and effector neurons.

Unlike other cells, neurons do not replicate in the post-natal period. This means that the brain must be equipped at birth with enough neural elements to handle a lifetime of experiences. Anatomical examinations reveal that the human brain contains about ten billion neurons, each of which connects typically to many other neurons. The number of interneural connections is not fixed. It varies among neurons and increases as the organism grows. For man, this increase is particularly dramatic in the period between the ages of 15 and 24 months (Ref. 24). Estimates place the overall memory capacity of the human brain at about 10^{15} bits (Ref. 27).

Behavior of individual neurons is of two kinds: excitatory and inhibitory. Excitation corresponds to the action of a neuron stimulating an adjoining neuron to discharge its potential and generate an electric impulse. Inhibition corresponds to an action preventing such a discharge. In case of multiple interneural connections, as is usually the case, a neuron will discharge if, and only if, the net amplitude of all excitatory and inhibitory influences received at any one of its terminals exceeds the activation threshold of that terminal (Ref. 28).

Theoretical work has verified that by assigning suitable activation thresholds at the receptor-central and central-effector neural junctions, nerve networks can be synthesized satisfying any given input-output relationship that can be exhaustively and unambiguously specified (Ref. 28). On the basis of this finding it it not unreasonable to suggest that the unorganized brain at birth is progressively modified by processes which selectively alter activation thresholds at neural junctions. This continuous modification is accelerated every time the organism is exposed to a learning situation.

In terms of CNS activity, rather than individual neuron performance, one of two types of excitatory or inhibitory states is invoked by a stimulus: local or general (Ref. 29). Localized excitation, or inhibition, corresponds to a relative elevation, or depression, of neural discharges restricted spatially to the projection area receiving the stimulus. Obviously, the area type (e. g. visual vs. auditory) is determined by the sensory modality through which the stimulus is exercising its influence. Generalized excitation, or inhibition, corresponds to a relative elevation, or depression, of neural discharges extending to all projection areas irrespective of the sensory modality presenting the stimulus.

Electroencephalographic studies of brain-wave patterns reveal that these four types of CNS states are invoked by distinct types of stimuli (Ref. 30). Generalized excitation occurs in response to a novel (first time) stimulus of any degree of intensity or to a very intense stimulus, regardless of familiarity. Localized excitation occurs in response to a conditioned stimulus or to a positive or negative unconditioned stimulus of familiar origin, all of moderate intensity. Localized inhibition develops in response to a conditioned stimulus presented consistently without reinforcement, to a sufficiently repetitive or prolonged familiar stimulus, or to reciprocal action of another projection area, itself activated by a conditioned or unconditioned stimulus. Generalized inhibition develops in response to a rhythmic stimulus presented continuously, to a novel stimulus immediately after it has been categorized, or to a novel stimulus which may not yet have been categorized (assigned a meaning), but whose application has been excessively prolonged.

Generalized excitation is expressed behaviorally in terms of an unconditioned response complex called the orienting reflex (Ref. 13, 21 and 29). Under the influence of this reflex the individual appears surprised, interrupts its ongoing activities, assumes a characteristic inquisitive attitude of non-specific attention and attempts to identify what the stimulus is and what its possible consequences might be. Conscious processes are also brought into play and sensory modalities competing for CNS access are sampled for clues on a random basis. This behavioral mode allows the individual to collect and discriminate the variety of data he needs to achieve stimulus recognition and evaluation. Additionally, while the orienting reflex is active it inhibits the release of conditioned reflexes. The persistence of learned behavior in a situation potentially different from that under which such behavior was originally learned, can be useless if not potentially harmful. Thus, learned behavior is temporarily discontinued as soon as a novel stimulus is perceived and while it is being evaluated. This blockage of conditioned reflexes is called external inhibition (Ref. 13).

The orienting reflex persists for as long as the condition represented by a novel stimulus remains undefined and until either the significance of the stimulus in terms of consequences is eventually understood, or neural fatigue develops and forces the brain to pass into a state of reciprocal inhibition.

After a novel stimulus has been categorized, subsequent presentations invoke localized, rather than generalized, excitation. This change in the excitatory mode is an indicant of habituation. Localized excitation is expressed behavorially by a decrease, or even interruption (depending on stimulus intensity and significane), of ongoing activities and by selective focusing of attention on the source of the stimulus (stimulus information is preferentially transmitted to the appropriate projection area corresponding to the receptor sensory modality).

Repetition or prolonged continuous presentation of a stimulus tends to induce a state of local inhibition in the corresponding projection area of the brain. Arriving signals are blocked-off and their transmission from sensory organs attentuated if, the information they convey is overly redundant wasting neural effort, or if their further acceptance threatens the brain with neural fatigue. Signal attenuation appears to be the result of an increase in activation threshold values at the sensory-neural junctions. Behaviorally, an individual in a state of inhibition exhibits no overt awareness of the stimulus.

The assigned significance of conditioned stimuli is constantly re-evaluated so that when a given stimulus ceases to conform with established correlations the organism inhibits it and the stimulus becomes temporarily or permanently ineffective. A stronger local inhibitory process is required to overcome the more intense excitation process invoked by a strongly conditioned stimulus and the greater must be the number of unreinforced presentations necessary to bring about complete extinction. This type of progressive weakening of response to a conditioned stimulus is called internal inhibition (Ref. 13).

Inhibition is also responsible for forgetting. Unlike short-term memory loss, central long-term memory lapses apparently involve a "covering over" or "locking-up" mechanism, rather than an "erasing" process, since experience confirms that it is possible to recover many "lost" memories (Ref. 24).

Generalized inhibition can be considered as an escalation of localized inhibition spreading-out over the entire cortex under monotonous or exhaustive situations. In the absence of distracting stimuli the inhibitory process will remain operative leading eventually to sleep.

Sleep is a behavorial state characterized by a loss of critical reactivity to events in the environment, a reduction of muscle tone and an alteration of conscious processes. The functional purpose and operative mechanism of sleep are still obscure (Ref. 24). What is known is that during sleep the brain shows modifications in the organization of its activities, as evidenced by electroencephalographic (EEG) responses. Conversely, the total activity level of the brain remains practically constant during both sleep and waking states

(Ref. 31). It is also known that sleep is not a uniform state. Rather it is manifested under four different stages of increasing depth, each stage characterized by distinct EEG responses and eye movement patterns (Ref. 31). Nightly sleep is also rhythmic, consisting of 90 to 120 minute cycles during which a person moves from one sleep stage to another repeatedly throughout the night (Ref. 4).

The intensity and efficiency of behavioral reactions to stimuli (i.e. level of performance) has been shown to increase with increasing level of arousal, or alertness, (i.e. degree of neural excitability) up to a limiting value (Ref. 29). Beyond this value, further increases in arousal, or alertness, lead to a decrease in the quality of the response, both in terms of reaction time and response effectiveness. This is shown schematically in Figure 1.

The level of arousal depends on four groups of factors. The first group includes the physical characteristics of the stimulus (or combination of stimuli) eliciting the excitation. The less familiar, the more intense, the less repetitious or less prolonged a stimulus is, the higher is the resulting arousal level.

The second group involves the significance of the stimulus (or stimuli) to the individual. The more positive or more negative a stimulus is, the higher is the resulting arousal level.

The third group has to do with the particular personality type of the individual responding the stimulus. Individual personalities vary between high and low arousability (Ref. 29). The difference lies in the relative ease with which a stimulus can invoke neural excitation and in the capacity of participating neurons to withstand long and intense excitation without passing into a state of inhibition. These personality traits appear to be partly hereditary and partly conditioned. The differences result from individual variabilities in activation threshold values at neural junctions. These variabilities cause individuals of high arousability to be particularly susceptible to external inhibition (inability to maintain concentrated attention in the face of distracting stimuli). Conversely, less excitable individuals are able to ignore stimuli to which more excitable ones are forced by nature to respond. This suggests that in situations of low intensity stimuli individuals of high arousability will perform better than individuals of low arousability and that in situations of high intensity stimuli, the reverse will be true.

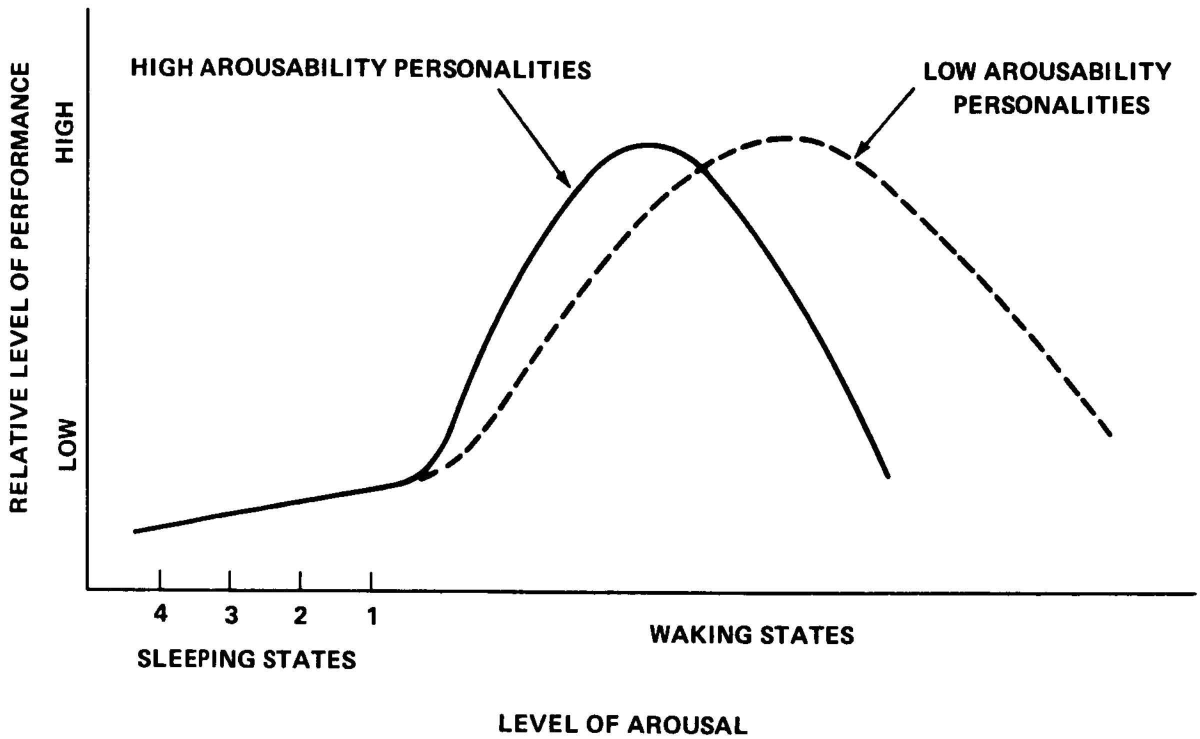

FIGURE 1. PERFORMANCE LEVEL AS A FUNCTION OF AROUSAL LEVEL AND PERSONALITY TYPE

The fourth group of factors includes the physiological state of the individual, any administered medication*, and preceding stimuli whose after-effects have not entirely disappeared. These factors collectively determine the background excitability of the brain. The brain can set the ongoing levels of neural excitability in the cortex and thus regulate the sleep-wakefulness cycle. Control of neural excitability is achieved by decreasing or increasing proportionally the activation threshold values of all neural junctions in the cortex (relative relationships remain unaffected). Changes in the internal environment as a result of fatigue, disease, injury, medication or physical stressors affect the brain and effectively modify cortical excitability. Additionally, every perceived stimulus, however rapidly it may terminate, has some aftereffects which tend to cause its inhibitory or excitatory influence to persist (Ref. 17). Aftereffects last from minutes to days, depending on the significance and intensity of the causative stimulus. On account of all this, the reaction to the same stimulus presented at different times may vary depending on the background excitability of the brain.

As a preliminary step to cognition, sensory information arriving at the appropriate projection area is encoded in terms of the local excitation it induces. The intensity of this excitation is determined by the collective influence of the first three aforementioned groups of arousal-modifying factors. Local excitation is, of course, equivalent to local arousal and, when a stimulus is presented, the latter will rise in amplitude above the plateau of general arousal characterizing the waking state (i.e. above the momentary background excitability of the brain controlled by the fourth group of arousal-modifying factors). Thus, arousal appears to be two dimensional. One dimension involves variability at the local level, causing attention to be focused upon a specific target. The other involves variability at the general level, corresponding to non-specific attention anticipatory of normal events.

Cognition is more than a mere passive process involving the reception and recognition of incoming stimuli. Rather, it is an active, model-building, goal-deciding and priorities-determining function directed towards reconstructing the environment, predicting future organism-environment states and organizing the release of adaptive responses. Each of these component functions will now be discussed separately.

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*CNS stimulants, such as caffeine tend to increase the intensity of the excitatory process.

It is generally agreed that the representation of the external world in consciousness is partial, rather than complete. Awareness of things and events in space and time is achievable through internal models, mental creations so to speak, which represent only those selected parts of the world outside that are significant to the individual. Consequently, the ability of people to interact effectively with the environment depends upon the accuracy and adaptability of their internal models, whereas their ability to communicate meaningfully with others depends upon the existence of common features in these models (Ref. 22).

Models are formed by afferent systems participating directly in cognition and disseminating the meaning of the arriving information, once understood, to memory banks for storage and subsequent use (Ref. 24). Two types of data are stored in models, but both types are differentially involved in all behavioral manifestations. These are: perceptual and motor. Perceptual data contribute to the recognition and evaluation (e.g. meaning assignment) of a stimulus input. Motor data control the coordination of neuromuscular responses.

Models can be based on subjective or incomplete interpretations of external realities and, therefore, may contain inaccuracies. Model imperfections are manifested as occasional errors in predictions. Normally, if a prediction proves wrong, the corresponding model is suitably modified (or altogether rejected) in an attempt to account for the apparent discrepancy between the real world and its internal representation. Learning can then be regarded as the ability to build and refine models. Similarly, memory is the ability to retain (i.e. store information in context) and retrieve models as required.

Models tend to be corrected everytime a <u>non-symbolic</u> stimulus is recognized as novel. However, in some <u>symbolic</u> situations arising during social interaction, stimulus novelty does not necessarily lead to model update. Cognitive dissonance or conflict may induce an individual to distort or reject novelty if its admission proves diminishing for his self-esteem or devastating for his ego (Ref. 32). Rejection or acceptance of novelty takes place early during the perceptual process and prior to the application of any conscious judgment. If stimulus novelty is accepted, then, depending upon its subjective meaning, it can invoke one of two responses: re-evaluation and update of existing models (individual accepts the change and incorporates the information), or non-correspondent behavior (individual resists the change, blocks the perceptual process and rejects the stimulus). Alternatively, if novelty is rejected despite the fact that it exists, then the significance of the stimulus is perceptually distorted and forced into conformity with existing models. Thus, at times, model rigidity can make people the victims of their own convictions and prevent them from correcting misconceptions which they accept as truths.

For voluntary learning to be possible the following conditions are necessary: an appropriate general arousal level must prevail, a novel stimulus must be acting, stimulus novelty must be accepted and stimulus significance must be important enought to induce motivation. Alternatively, a stimulus presented repeatedly with reinforcement will lead eventually to unvoluntary (automatic) learning.

Decision-making is an indispensible part of the cognition process (Ref. 33). Answers are sought to clarify a series of uncertainities facing the individual and decisions are made concerning: (a) the significance of the stimulus (i.e. whether or not it represents a threat, need or problem), (b) the establishment of a definable goal* consistent with perceived conditions, (c) the selection of an appropriate response and (d) the effectiveness of the response as judged by its consequences.

Absence of drive due to threat, need or problem, does not require the establishment of a goal and, therefore, no decision process is required at this stage. In the opposite case, a goal must be established and decisions made aimed at determining the most beneficial goal and establishing whether the premises are sufficient for problem solving. If the premises are insufficient the question arises whether they could be augmented. If not, a decision is made that the problem is unsolvable and the search for additional premises ends. If they can be augmented, additional premises are sought and, once obtained, the problem solving effort begins. If appropriate response data are already stored in the brain as a result of a previous exposure to the same situation, they are retrieved and used. Otherwise, the formulation of appropriate response algorithms is initiated either on a completely novel basis or by recombining available elemental responses into a new integrated whole. Decision to terminate activity towards the fulfillment of an established goal is reached as a result of aspiration achievement (perfect match between goal desired and goal achieved), satisfaction (well enough match), impatience (best match reached within a specified length of time) and discouragement (procedures and strategies to attain a match have been tried and failed).

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*The motivation for establishing a goal is attributable to a drive. Note that the drive must be evoked some time before its satisfaction becomes essential to survival so that sufficient time is available to find a way of achieving this.

The brain is functionally organized in such a way as to process incoming stimuli sequentially. In other words, full attention cannot focus simultaneously on more than one stimulus at a time be it external or internal. Yet, the individual lives in an environment rich in unanticipated hazards and unpredicatable opportunities whose perception in many instances, cannot be delayed. To assure timely response, an alerting mechanism in the brain interrupts attention to the on-going activity whenever real-time requirements of higher priority arise. This interruption makes it possible to redirect behavior towards goals judged more pressing or important (Ref. 34).

Successful operation of the alerting mechanism requires that a certain amount of sensory scanning go on continually at the sub-conscious level, otherwise external stimuli important enough to warrant task priorities reassignment, may remain unnoticed. Studies confirm that the various sensory modalities are processed on a time-sharing basis, each separate perceptual process lasting for at least 0.1 to 0.2 sec. (Ref. 33).

As more experience within a given situation is acquired, the frequency with which the alerting meachanism is activated, decreases. What appears to happen is that multiple side conditions are incorporated into this mechanism to prevent unwarranted activations from occurring. Also, as behavior is improved with practice, the number of activations arising from over-or under-responding, diminishes accordingly.

Considering the complexity of reaction patterns to stimuli, it becomes rather obvious that understanding of behavior requires at least some understanding of the physiologic mechanisms involved in selectively resetting the activation thresholds of appropriate neural junctions, every time a significant enough stimulus is perceived. Although present knowledge remains primitive, some progress has been reported in recent years.

It is now clear that the propagation of electrical impulses (and, therefore, information) from one neuron to another across their junction (synapse), is chemically controlled. Transmitter substances have been identified and shown to include cathecholamines (hormones) locally and selectively secreted in the brain (Ref. 36). Inhibitory states may be associated with an absolute or relative deficiency of cathecholamines, particularly norepinephrine, at functionally important neural junctions. Conversely, excitatory states may be associated with an excess of such amines. Furthermore, psychoactive drugs (tranquilizers, stimulants and hallucinogens) known to inhibit or facilitate the metabolism of transmitter substances in specific ways, were also found to modify behavior in corresponding ways (Ref. 24, 26 and 37).

Cathecholamines involved in behavior are synthesized directly in the central nervous system and exhibit diurnal rhythms. The rhythms are highly specific in terms of brain sites suggesting that regional periodicities are independently regulated (Ref. 4). Certain of the brain amines also fluctuate in rhythms that are out of phase as for example in the case of norepinephrin and serotonin. Additionally, a barrier exists at the blood-brain interface to prevent peripheral hormones, secreted into the general circulation system in response to body demands, from entering the cortex and exerting directly widespread central effects.

The mechanisms responsible for regulating the concentration of amines in the brain are still obscure. Complicating the picture still further is the unexplained mechanism of model formation, storage, access and retrieval.

In summary, behavior is controlled by the arousal level of the waking brain and the organization of neural networks in terms of input-output specifications. Arousal level is regulated chemically in accordance with self-derived and externally imposed influences. The organization of neural networks is regulated rigidly in accordance with genetic instructions and dynamically on the basis of cummulative experience.

STRESS

DEFINITION OF STRESS

Under normal circumstances an individual is in dynamic equilibrium with both its physical and sociocultural environments. In other words, he tends to maintain homeostasis and his behavior does not generate a back-flow of negative stimuli, either internal or external.

At times, however, situations arise which upset this equilibruim and compel its restoration. The individual is then faced with a problem, the solution of which depends upon the inherent solvability of the problem and the availability of adequate resources (physiological reserves, knowledge or tools). Obviously, symbolic stimuli can be interpreted differently by different people and, therefore, the judgment as to whether or not they represent a problem necessitating resolution, is highly subjective.

Considering now the process of problem-solving it is important to recognize that both time and effort must be expended before equilibrium can be restored. Stress is the state of greater or lesser mobilization of resources invoked in an effort to reinstate equilibrium when lost. It consists of a series of adaptive reactions lasting for as long as the problem of equilibrium remains unresolved. In case of successful problem solving stress disappears. Conversely, if the problem remains unresolved stress persists, leading eventually to pathology.

Attainment of equilibrium with either of the two environments must also be viewed with respect to equilibrium in the other. It is possible that sociocultural equilibrium is maintained at the expense of physiological homeostasis and vice versa (Ref. 38).

INTERNALLY ADAPTIVE REACTIONS

Physical, chemical, mechanical, biological (infectious) and social factors causing the disruption of homeostatic and/or sociocultural adjustments are called "stressor agents" or simply "stressors".

Two types of physiological responses to stressors are distinguishable: local and systemic. The former is normally invoked by non-symbolic stimuli only, while the latter by both symbolic and non-symbolic stimuli.

If the action of a local stressor, such as infection or injury, is selectively restricted to a small anatomical site, then the tissues directly affected will respond in a standard way. This defensive response syndrome of non-specific causation is characterized by tissue inflammation, which includes local swelling, reddening, heat and pain. During local infection, for example, inflammation develops in an effort to confine the penetration of microbes around the point of entry and prevent their spread. Concurrently, alarm signals are transmitted to regulatory centers which respond by releasing pro-inflammatory hormones able to affect damaged tissues only. If the local response is unsuccessful and infection involving large portions of the body is imminent, then a generalized non-specific hormonal reaction is triggered. Among its other beneficial effects, this generalized reaction also inhibits local defenses through the release of anti-inflammatory hormones. This is necessary whenever damage has spread beyond the control of local defenses. Inflamed tissues and organs are functionally impaired, release toxic by-products and, therefore, may endanger life if inflammation is allowed to involve large body areas.

Systemic responses are invoked every time a stressor causes changes in the internal environment by acting either directly upon it or upon one or more of the physiologic organs or systems regulating homeostasis. However, all organs or systems are not affected equally by any given stressor. For another, the incubation period between the time of initial provocation and overt symptoms also varies with the organ or system. For example, four major modes of death have been recognized in humans following lethal radiation exposure (Refs. 39, and 40). Doses between ∿300 and ∿1000 rads tend to induce failure of the blood forming organs leading to death within 60 days following the exposure. Doses between ∿800 and ∿3000 rads tend to result in gastrointestinal mucosal loss leading to death within 5 days. For doses between ∿2000 and ∿10,000 rads death is attributable to vascular damage and occurs within 48 hours. Finally for doses over ∿7000 rads death is attributable to central nervous system disruption and occurs within 24 hours. Thus, the complex symptomatology observed in many diseases may be in part due to the differential response, in both time-course and amplitude, of various physiological systems or functions to a common stressor.

It is also important to recognize that direct functional impairment of a single organ or system can lead to a cascade of failures in other organs or systems. Thus, it is not always immediately obvious that certain disorders are caused by the action of a seemingly unrelated stressor. The word "abscopal" is sometimes used to describe the indirect failures that occur in organs at a distance from the anatomical site of primary or direct injury (Ref. 41). For example, malfunction of immunological processes can cause secondary injuries and even jeopardize survival by mobilizing defense mechanisms against the body itself. Rheumatiod arthritis is a case in point (Ref. 42).

Systemic responses are of two kinds: specific and non-specific. Specific systemic reactions correspond in character to the particular type of stressor acting. Cold, for example, causes shivering and peripheral vasoconstriction while heat causes sweating and peripheral vasodilation. If, however, either stressor is intense enough or persists long enough, additional systemic responses common to both will be induced (e.g., increased cardiac output). These additional responses are non-specific in the sense that they can be invoked by almost all types of stressors.

Systemic responses are much more complex than the local ones, and also less well understood. What is important, however, is that apart from the specific and characteristic reactions to different kinds of stressors, the body responds to emergencies in a rather basic, stereotyped way. This stereotype or non-specific response has been shown to follow a three state course called the "General Adaptation Syndrome" (Ref. 43).

a. The Alarm Reaction - Immediately upon the application of an intense stressor, the body experiences shock, characterized by such symptoms as reduction in the level of performance, decrease in muscular tonus, decrease in blood pressure, decrease in core temperature and chemical alterations in the composition of the internal environment. The severity of these changes increases with increasing stressor intensity. In extreme cases of excessively intense stressors, shock can cause instantaneous death. In less dramatic situations the body responds quickly by mobilizing defense mechanisms which restore some measure of equilibrium by correctively adjusting such parameters as blood pressure, pulse rate, respiration rate and depth, general metabolism, blood sugar levels and central nervous system excitability. These emergency adjustments are controlled by quick-acting, short-lasting autonomic nerve impulses and slower-acting, longer-lasting hormonal stimulations. Both are instrumental in bringing about a state of counter-shock, characterized by individual differences in the total amount and relative ratios of the various hormones secreted (Ref. 45). This helps explain why phsiological resistance to one and the same stressor varies between individuals. If prolonged or excessive, the alarm reaction can lead to disorders.

b. The Stage of Resistance - The counter-shock phase of the alarm reaction is designed to provide the body with the extra time it needs to solve the problem it faces. Problem-solving entails identification and mobilization of specific defenses best suited to counteract the effects produced by the particular type of stressor acting. For example, if a bacterial infection threatens well-being, the body must produce antibodies and render the internal environment inhospitable to the infectious organisms. If, alternatively, the threat comes from extreme temperature changes, the body must activate the situationally appropriate thermoregulatory and metabolic mechanisms. Once specific defenses are brought into action, optimum resistance (acclimatization) to the emergency situation is achieved and stess hormones, no longer critically needed, reduce to levels only slightly above normal. The stage of resistance can be long-lasting and need not be pathologic.

c. Stage of Exhaustion - Specific defense mechanisms have a wide range but not unlimited regulatory capability. If the acting stressor is too intense or persists too long, these mechanisms will eventually fatigue and perform inadequately. Symptoms of functional degradation like those observed in the shock phase of the alarm reaction will then re-appear and life will continue for as long as emergency reserves are available.

Figure 2 is a representative schematic illustrating the general features of the General Adaptation Syndrome triggered by exposure to lethal doses of radiation.

Non-specific systemic stress is invoked in response to different stressors. These can be of four types: external non-symbolic (physical discomfort or injury and perception of threat of discomfort or injury), internal non-symbolic (loss of homeostasis), external symbolic (sociocultural pressure or perception of sociocultural threat) and internal symbolic (thoughts or imagery producing psychological tension). Obviously, the interpretation or meaning given to symbolic

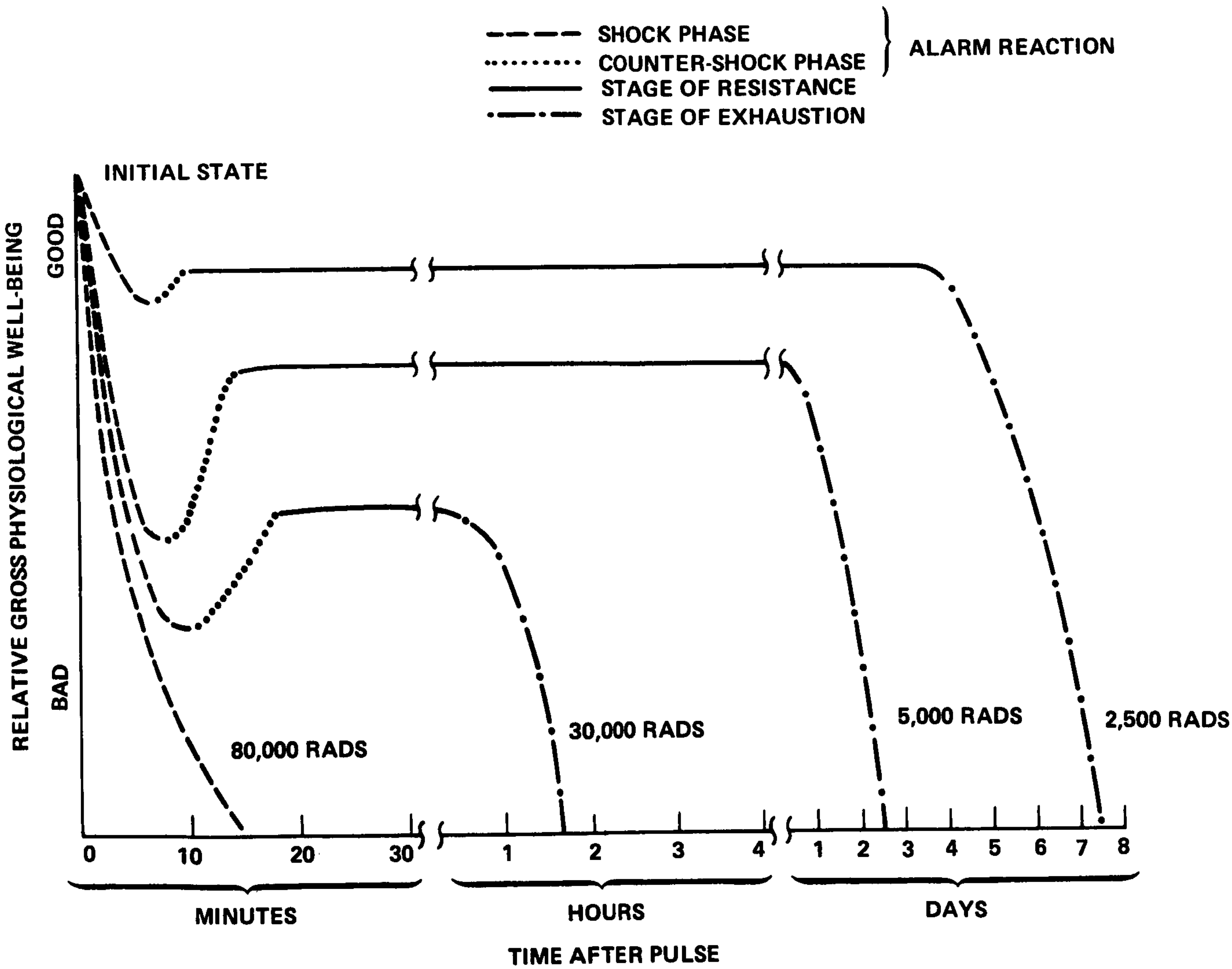

FIGURE 2. SCHEMATIC ILLUSTRATION OF GROSS PHYSIOLOGICAL DEBILITY IN THE MACACA MULATTA FOLLOWING EXPOSURE TO A RADIATION PULSE AT TIME ZERO

stimuli, either internal or external, is highly subjective and, consequently, the invoked response is highly conditioned. In a sense, each individual develops his own special response patterns to the stresses of life.

Ideally, the intensity of a stressor and the implitude of the corresponding stress reaction it invokes are closely related (Ref. 43). If this relationship is altered by over- or under-mobilization of defenses (stress hormones) as a result of conditioning or some internal organ malfunction, then severe physiologic disturbances may occur in otherwise midly stressing situations. For example, plant pollen introduced into nasal passages causes some people to suffer from a stuffed nose, itching eyes, frequent sneezing, weeping and other symptoms. Yet overreaction to pollen, rather than the inherent properties of pollen itself, is responsible for these symptoms.

Over- or under-availability of stress hormones can also rise regionally, simply because hormones tend to circulate evenly throughout the body. Whenever a stressor (e.g. radiation) affects differentially the various anatomical regions of the body, then the concentration of hormones optimally needed for resistance also varies among regions.

In the struggle for survival, systemic stress invoked by mere perception of an undesirable or threatening circumstance has evolved for a particular functional purpose. Namely, to prepare the body for imminent vigorous physical action (i.e. flight or fight). The stress of modern life, however, is primarily caused by symbolic stimuli and, consequently, cannot be relieved in most instances by physical effort. Usually, one gets all tuned-up for activity but ends up making little or no muscular effort. Depending on the duration, intensity and frequency of exposure to such inopportune systemic stress, changes in physiologic systems may ensue which do not contribute to the needs of the individual. In fact, some of these changes can even be pathologic in themselves. Damage to the circulatory, renal, gastrointestinal and musculoskeletal systems is known to occur as a result of otherwise nonpathogenic, socioculturally derived, stressors (e.g. anxiety, worry, anger, fear, etc.) turned pathologic because of unwarranted intensification of altogether inopportune activation of systemic stress (Ref. 43).

Apart from the well documented fact that different individuals show different resistance to the same stresor, it is also observed that the same individual can tolerate differently an identical stressor presented at different times (Ref. 43). For example, the level of atmospheric oxygen that quickly would cause unconsciousness in a flyer at 4 p.m. affects him less at 4 a.m. (Ref. 4). All other conditions being the same, this intraindividual variation is attributable to the influence of diurnal rhythms (Ref. 45).

In a sense, the diurnal rhythm is a clock of changing vulnerability and resistance to stressors. Figure 3 shows the variation in physiological vulnerability of mice exposed to three different types of stressors. Each stressor was held at constant intensity and was presented to several population groups at different times over the 24-hour period (Re. 45). Clearly, "hours of maximum vulnerability", occurring at different clock times for different types of stressors, can be shown to exist within each daily cycle. In fact, for each of the many kind of stressors an individual can be exposed to there exist periods of increased or diminished resistance. Even the normal daily levels of adrenal (stress) hormones circulating in the blood or excreted in the urine are highest in the morning, diminish in the course of the day and reach their lowest point at night (Ref. 28). The same rhythm is observed in all biological functions controlled by the adrenal hormones. Consequently, a person may appear normal in the morning and abnormal (e.g. hypertensive, diabetic, etc.) by afternoon.

Susceptibility to disease can increase beyond the "normal" daily maximum and the hours of diminshed resistance shift in clock time if, either free-running conditions develop or if unusual living schedules are observed.

Diurnal variations in physiologic vulnerability to stressors extend to both the temporal and spatial domains. It is observed that the severity of the injury caused to a specific anatomical site (tissue or organ) by the same impulse stressor acting at different times, is also a function of clock time. Again, the hours of diminished resistance are a function of both type of stressor acting and anatomical site affected.

It appears that some stressors can alter physiological rhythms in amplitude, phase or even period and cause manifestations of disease symptoms. Medication can be beneficial in restoring rhythms to normal but drug toxicity or efficacy is also a function of the biological time of day. In many instances, a profile of a person's diurnal rhythms may be helpful for both diagnosis and treatment of a particular illness. For example, a study of catatonic* patients have revealed that

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*Catatonia is a mental disease characterized by swings from normal behavior to either hyperexcited/violent states or mute/frozen-like states resembling paralysis.

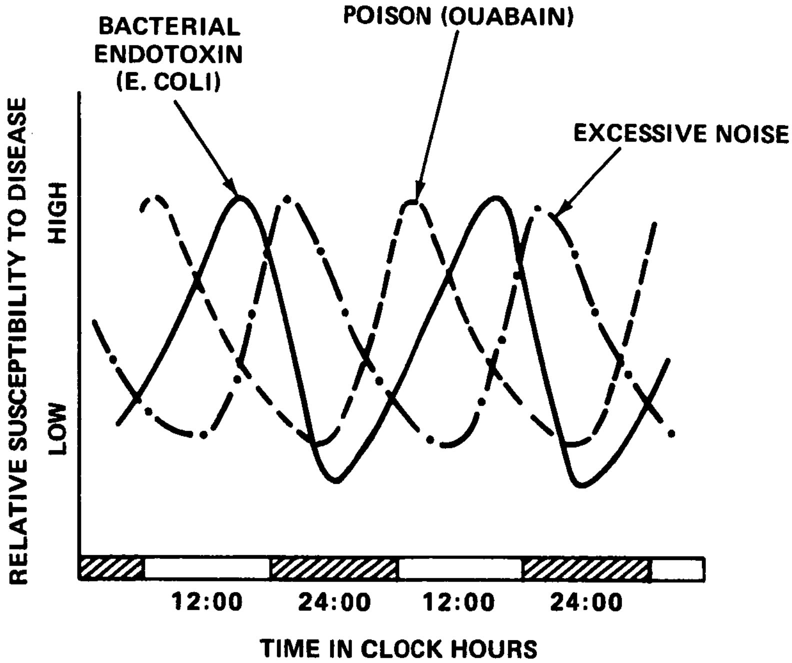

FIGURE 3. HOURS OF DIMINISHED RESISTANCE IN MICE TO THREE DIFFERENT STRESSORS

biochemical constituents excreted in the urine adhere to the normal 24 hour rhythm with the exception of sodium which adheres to a 22 hour periodicity (Ref. 4). It is most likely that such a metabolic desynchronization sets up a beat within the metabolic machinery that would explain the observed cycles in mood and behavior.

When several stressors act in combination, their effects can combine either synergistically enhancing the resulting injury, or antagonistically, reducing it. For example, administration of certain electrolytes in large quantities to rats produces no ill-effects. However, if an ordinarily nonpathogenic quantity of cortical (stress) hormones is also administer at the same time, the combination may cause severe disorders and even death.

Alternatively, if young rats are kept at room temperature and restricted to a certain type of low protein diet, they eat little, do not grow and eventually die within a few weeks. But if the same experiment is carried out at 5°C instead of about 20°C (room temperature), the rats do not only survive but even grow under the treatment (Ref. 46).

The term "Combined Injuries" refers to damage produced by exposure to at least two different types of non-symbolic stressors. In the latter case, it is justifiable to refer to a "Combined Injuries" effect only if the time interval between exposure to two successive stressors remains shorter than the time the body requires to recover from injuries sustained by the first of the two. The effect of stressors acting individually is diagrammed schematically in Figure 4. If the stressor does not overwhelm the defense mechanisms but is intense enough to trigger a systemic response, then general body resistance can be temporarily increased following recovery from the initial shock period. But, if the stressor is large enough, the compensatory capabilities are exceeded and the body resistance remains depressed until full recovery.

In combined injury situations, overall response is predominantly determined by the timing of stressor application. Consider, for example, a situation where two different, injury producing stressors of unequal intensity are applied for short periods at different times (Ref. 47). Three alternatives exist:

1. Both stressors are applied simultaneously.
2. The less intense stressor is applied first.
3. The more intense stressor is applied first.

If the two stressors are applied simultaneously (Figure 5) then their combined effects will be more severe than than the larger stressor acting alone. If the more intense

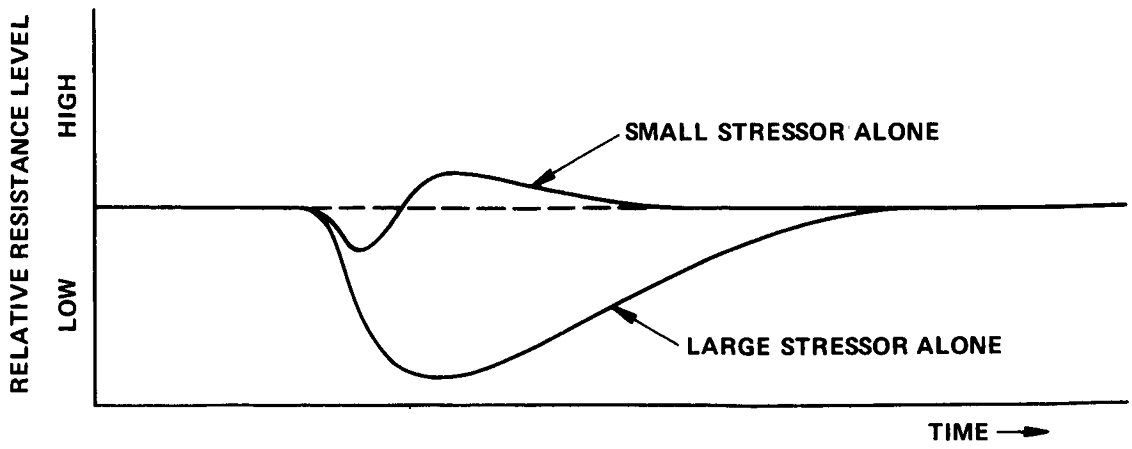

FIGURE 4 - TOLERANCE TO INDIVIDUAL STRESSORS

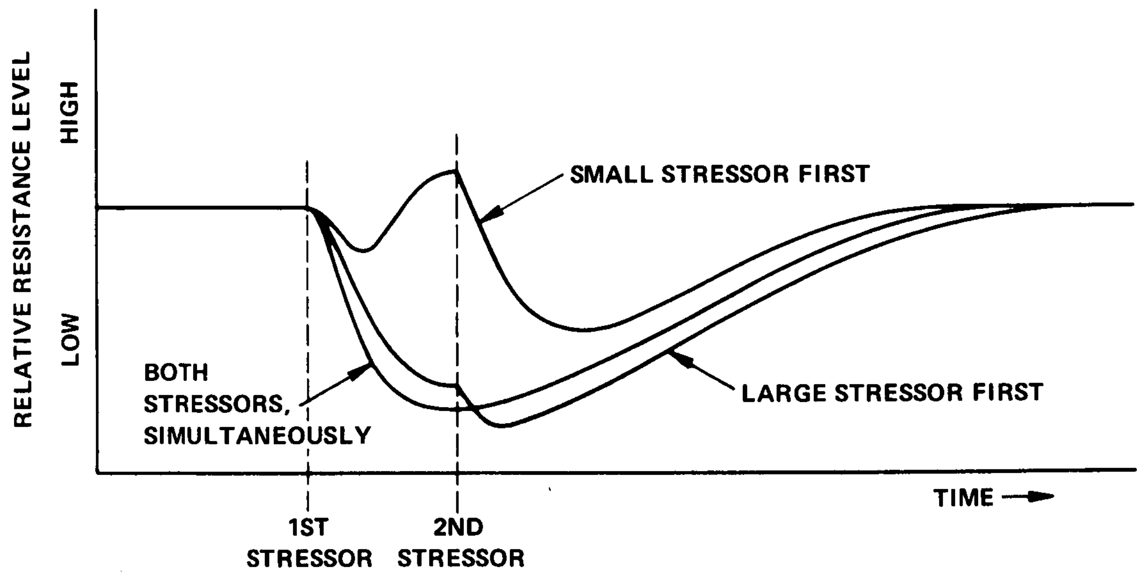

FIGURE 5 - TOLERANCE TO COMBINED STRESSORS

stressor is applied after the less intense one (when general body resistance is increased), then the combined effect will be less severe then the sum of the component injuries, had the two stressors been applied simultaneously. When the more intense stressor is applied first, an entirely different situation arises. Then, since general body resistance is already depressed, the combined effect will be more severe than the sum of the component injuries, had the two stressors been applied simultaneously.

What appears to emerge from this picture is that stressor significance in terms of biological impact, depends critically upon the physiologic state of the organism at the time of the exposure. Normally, the organism keeps a reservoir of emergency resources which have some delay time in responding to demand and are slowly replenished. Stressors induce a change in state and trigger the release of this reservior of emergency resources which contributes to the attenuation of harmful physiologic consequences. Thus, if the timing is right, a mild stressor may prepare the organism to resist better any subsequent intense stressors by overcoming the inertialof the defense mechanisms. Conversely, exposure to an intense stressor may be the cause of reduced resistance to other stressors applied at later times if resources are depleted faster than they are replenished.

Clearly then, at least two gross states of the body exist. One state is related to the non-stress situation, and the other to stress. In the non-stress situation, normal operation of all physiologic systems is maintained. In the stress situation, physiologic systems are attended on a priority basis. Those that are not immediately critical operate in a depressed mode* while others, including protective and recovery mechanisms, are stimulated into full action. Body readiness to cope with stressors depends upon its specific physiologic state. Stressors induce a change in state. Return to the pre-exposure state is initiated immediately upon stressor removal and proceeds gradually. Recovery is complete when the pre-exposure state is reached. Any residual irreversible changes must be considered pathologic corresponding to permament injury. Pathologic states are due to mismatches between stressor action and body reaction. Permanent injuries are caused by undermobilization of defenses. Diseases of adaptation result from overmobilization of defenses.

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*In extreme cases, even the arousal level of the waking brain is depressed to stretch the rapid depletion of resources. This results in general malaise and reduction in awareness of, and reactivity to, external events.

EXTERNALLY ADAPTIVE REACTIONS

From a psychological standpoint, two types of stressors are distinguishable: those threatening or confronting the body with physical discomfort or injury and those threatening or confronting personal cognitive models or accustomed behavorial patterns with subjectively undesirable change.

It is now known that besides activating autonomic and endocrine mechanisms, psychological stressors also activate situationally appropriate emotional centers* in the brain (Ref. 35). These centers elicit drives and, in extreme cases, direct behavior to follow one of two distinct modes of behavior: aggressive approach or fearful avoidance. Ideally, the displayed behavior is intended to reduce the intensity of the emotional drive by resolving the confronting problem.

Unfortunately, many of the problems facing man in modern society cannot be resolved easily. Threats arise from the sociocultural environment to challenge continually man's social role (self-actualization efforts) or self-image (self-actualization status). To maintain an emotional balance in the face of unfavorable circumstances an individual may employ such psychological defenses as rationalization, repression, denial or projection. Responses, however, must adhere to patterns of socially accepted behavior. Conformity to rules is enforced by additional threat of physical or psychological penalties designed to discourage deviations. Thus, cognitive awareness of stressors poses problems which, in many instances, must be resolved within multiple constraints. In this context, behavior can be regarded as an effort seeking to satisfy simultaneously a multitude of seldom converging external (social) and internal (personal) needs. The direction and intensity of the displayed behavior are determined by the subjective meaning assigned to the stressor, on one hand, and the physiological state, psychological status and personality type of the responding individual, on the other.

Perception of psychological threat or recognition of unfavorable cost-reward expectations may invoke anxiety (i.e. uncertainty of what to do next and what the consequences of alternative actions might be) if the individual lacks confidence

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*The existence of these centers has been demonstrated by the intense aggressive and fearful patterns of behavior displayed predictably by animals when specific areas of their brain are selectively stimulated by an electric impulse (Ref. 24 and 35). Affiliative approach is another type of behavior also associated with a corresponding emotional center.

in his problem-solving ability or cannot attend to problem-solving because of inadequate data. Under such circumstances he no longer feels secure. Ironically, stress resulting from anxiety or desperation is known to interfere with cognitive processes and may reduce even further a person's effectiveness in mastering a problem. For example, it can narrow down the perceptual field making the individual less aware of features in the environment that can otherwise help resolve his predicament (Ref. 48).

Alternatively, it is also observed that certain people create problem situations where none objectively exist. This is because they continually need reassurance of their problem-solving ability and, for them, lack of problems corresponds to stress (Ref. 38).

If a problem remains unresolved, tensions* build up and the situation is further compounded if these tensions are not discharged through appropriate channels (Ref. 38). Thus, failure to cope with the original problem may lead to a secondary problem of unresolved tensions. Alternatively, if a solution to the main problem is attempted but backfires then, the suffered consequences may lead to more precipitous, less adaptive, more painful responses when a similiar situation recurs((Ref. 34).

Behavioral abnormalities can arise as a result of prolonged conflict or exposure to a persistently intense negative stimulus. Conflict occurs when two incompatible demands are imposed simultaneously on an individual so that resolution of one denies resolution of the other.

Confronted with conflict or an intensely negative symbolic stimulus the individual is motivated to respond. He may choose to meet the demands of the problem directly by trying one or more solutions. Alternatively, if he feels that a direct solution is unattainable (lack of resources) or undesirable (leads to another worse predicament) then, he may attempt to live with the problem or distort reality to make conditions subjectively tolerable. In either case maladjustments can be expected to occur including classically or operantly conditioned symptoms. If a solution is unattainable then tensions will build up and eventually discharge through irrelevant channels. These can be both symbolic (e.g. verbal aggression, sarcasm, etc.) and non-symbolic (e.g. muscular

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*Tension is a state of inopportune mobilization of physiological reserves and elevation of the cortical arousal level (increase in the background excitability of the brain). The former can lead to diseases of adaptation and the latter to performance decrements and insomnia.

activities, physical aggression, sexual engagements, etc.). If identifiable solutions can lead to worse predicaments, then the problem's importance, or even existence, is denied, so that the need to be concerned with it (at least consciously) is temporarily, or permanently postponed. This self-deception is accepted under the pretense of a warranted re-evaluation of previously misinterpreted facts. It usually leads to incorrect decisions, tension and inappropriate behavior, further aggravating the overall problem.

There is evidence to suggest that in addition to physical stressors, intense psychological stressors may also alter the amplitude, phase and even period of physiological rhythms causing beat phenomena and eliciting periodic disease symptoms either on a temporary or permanent basis (Ref. 4).

In general, the definition of equilibrium with respect to the sociocultural environment, varies between individuals. It is a desired subjective state towards which one continually strives, but rarely reaches or maintains for long.

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APPENDIX B

SOME PHYSIOLOGICAL CONSIDERATIONS OF SPACE FLIGHT

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SOME PHYSIOLOGICAL CONSIDERATIONS OF SPACE FLIGHT

Physiology as a Scientific Discipline

Physiology is a body of knowledge concerned with processes which account for survival of living systems. Regardless of how complex or simple a living system may appear, it always possesses certain characteristics and capabilities. The natural phenomenon which we call life is in reality a dynamic organization of processes constantly seeking equilibrium with the environment. All forms of life as presently exist on this planet represent the end product, so to speak, of many eons of evolutionary adaptation to the earth environment. The present terrestrial environment in which man finds himself, however, was not always so constant a milieu. There is abundant geological evidence, for example, of drastic temperature fluctuations which have been foisted upon the earth's animal and plant species. Those forms of life capable of adapting to such dire changes survived; those which could not, perished, and are known to us today only as fossil relics of eras long past. But no such cataclysmic changes in man's earthly surroundings have occurred during historical times, with the possible exception of the great flood recounted in the Bible, and man has largely taken for granted those conditions which are permissive of, or compatible with life as he experiences it today. It is only when these conditions change rather precipitously, either naturally or by artificial design, that man becomes acutely aware and appreciative of the many forces of nature to which he is constantly subjected, to which he has become so well adapted, and which forces he must take into serious account, if indeed he is to survive such potentially lethal changes.

In his invasion of space, man today experiences just such a drastic and sudden change of environment; he is exposed to extreme temperature fluctuations, to a nearly complete vacuum, to essentially null gravity, to disruption of the familiar circadian rhythm cycle, to changes in electromagnetic and radiation fluxes, and to accelerative forces on launch and re-entry many times the force of gravity. His environment in space then may clearly be classified as hostile. There is no protective atmosphere to absorb ultraviolet and other harmful radiation, to help dissipate the highly energized cosmic particles from periodic solar flares, or to effect the oxidative disintegration of potentially hazardous showers of particulate matter (macro- and micrometeorites). Faced with this impressive array of adverse circumstances, man, in order to negotiate successfully such conditions inimical to life, must surround himself with more familiar and friendly environmental conditions to which he has become accustomed through

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*Primary preparation of this appendix was by NASA-MSC/DA.

many centuries of adaptation. These benign conditions are provided by his spacecraft with his complex of life support systems.

Provided here is a brief listing of the more important physiological subsystems along with their anatomical components.

Physiological Subsystems

SUBSYSTEM	ORGANS	FUNCTION
Cardiovascular	Heart, Blood Vessels	Perfuse Tissues with Blood
Reticuloendothelial	Blood Forming	Red & White Blood Cell Production
Respiratory	Lungs	Provide Gas Exchange between Cells and Environment
Musculoskeletal	Muscles, Bones	Provide Framework and Motion
Special Senses	Eyes, Ears, Vestibular System, Taste Buds, etc.	Sense the Environment
Nervous	Brain, Nerves	Receive Excitation from All Systems and Perform Purposeful Integration
Gastrointestinal	Mouth, Stomach, Alimentary Canal	Ingestion, Digestion Absorption, Excretion
Renal	Kidneys	Regulate Composition of Plasma
Endocrine	Endocrine Glands	Regulate Chemical Processes, Growth, etc.
Integumentary	Skin	Protect Tissues and Assist in Temperature Regulation

Obviously in this paper we cannot hope to discuss fully the disturbances to or reactions of all of the listed physiological subsystems, nor can we hope to describe fully all of the stresses listed above; rather, we shall select a few representative physiological systems and describe in modest detail how the stresses which characterize space flight may influence these systems.

THE PATH INTO SPACE MUST, PER FORCE, BE THE PATH ALREADY PARTIALLY TRAVELED

The early forms of life on earth developed in the water. There were very simple life systems, often unicellular and obtaining oxygen and nutrients directly from the water to sustain the metabolic chemical reactions characteristic of living systems. A simple vascular system emerged making it possible for the animal to increase in size and complexity by bringing life-sustaining nutrients to cells distant from the interface with the water. A simple pump evolved in the vascular system and along with valves it became possible for cyclical muscular contractions to pump the nutrient fluid around a circuit which may be viewed as a closed loop with the metabolizing cells in one portion and a large diffusing surface in contact with the environment in the other.

As the organism increases in size so increases also the total surface area of all of the cellular components which comprise the organism. The exchange of oxygen and carbon dioxide as well as nutrients and the by-products of cellular metabolism takes place at the cell wall, the interface between the vascular system and the cell. Thus as the surface area of the cells increases, it becomes necessary to increase the surface area of the interface between the vascular system and the environment, and primitive gills began to develop. Thus the function of the gill is to provide a large surface area in contact with the environment and this surface area must be roughly equivalent to the surface area of all the cells contained in the organism.

Oxygen in the water is obtained from the air in amounts equal to the solubility of oxygen in water and the partial pressure of oxygen in the air over the water. Because carbon dioxide diffuses rapidly across biological membranes, the evolving marine animal was faced more with the problem of obtaining an adequate oxygen supply than in disposing of carbon dioxide as a gaseous by-product of metabolism. An oxygen sensing mechanism was developed which in the fishes is found in the branchial arteries which perfuse the gills. Nervous connections from this oxygen sensitive area supply the brain with information about the amount of dissolved oxygen. Thus, swimming movements could be purposely directed to regions with higher oxygen tension. If a carbon dioxide sensor actually exists in fishes and other marine forms, it has not been well described. Indeed a carbon dioxide sensor which would inform the brain that the level of carbon dioxide in the tissues and blood was reaching an alarmingly high level is not required because the high diffusion rate of carbon dioxide across gill prevents its accumulation in the tissues.

In a single species of animals, one can readily identify a wide range of individual variations, not only in structure but in function as well. This wide range in individual variation makes it possible for certain individuals to cope more effectively with adverse circumstances imposed by the environment. The development of a primitive lung may represent one example of how the chance variation in anatomical structure made it possible for the lung to develop and for animals to leave the water and breathe air. In the study of embryology we learned that the primitive lung developed as a ventral out pouching from the anterior (forward) end of the primitive gut. The genetic retention of this chance anatomical variation, and its continued sophistication through millions of generations and natural selection, gave rise to the organ we now recognize as the lung.

Thus we see that acquiring by chance within the framework of individual variation a device or process which tends to potentiate viability makes it possible for an animal organism to explore beyond what may have been considered the ultimate boundary of its environment.

We are all familiar with the class of animals known as amphibia. It is characteristic of these animals that at some time in their life cycles they possess both gills and lungs and can live in water as well as in air. As we proceed higher in the animal kingdom, we note that in the reptiles, the lung is the organ by which gas exchange is carried out. Generally speaking, reptiles have very primitive lungs; that is to say, these organs have relatively small surface areas. These animals are also cold blooded (poikilothermal). Their body temperature tends to come into equilibrium with the temperature of the environment over quite a sizeable temperature range. We note also in the amphibians and reptiles (considered transitional forms) changes in the vascular systems which make it possible for blood to be pumped by one set of heart chambers and valves through the tissues of the body, and another set of heart chambers and valves to pump blood through the lungs for gas exchange.

When a marine animal leaves the water and comes into the land, other environmental factors intervene. While the animal resided solely in the water he was in an environment of approximately the same specific gravity as his body. The effects of gravity on the vascular system were essentially absent. In land animals the effects of gravity on columns of fluid in the vascular system required that mechanisms be invoked to make it possible for blood to return to the heart against the force of gravity. Because the veins are thin-walled and the venous system contains a large amount of blood, this portion of the vascular system is most susceptible to disturbance by the force of gravity.

RESPIRATION AND THE SELECTION OF SPACECRAFT ATMOSPHERES

The structure and function of the mammalian lung makes it eminently apparent that evolutionary processes have made it possible for this class of animals to live their entire lives in the sea of gas which surrounds the earth and which consists of approximately 21 percent oxygen and 79 percent nitrogen. The wide fluctuation in body temperature which characterized the poikilotherms is gone, and in its place we find a constancy of body temperature at about 37°C. The mammals have a fully developed 4-chambered heart, one-half of which pumps blood to the tissues after oxygenation in the lungs (the systemic circulation), and the other receiving deoxygenated blood from the venous system to be pumped into the pulmonary circuit for oxygenation.

Gas exchange takes place in the millions of tiny sac-like structures, the alveolae, which are surrounded by capillaries.

In the human lung the alveolar surface area is estimated to be about 50 sq. meters! By rhythmic emptying and filling of the lungs with atmospheric air, the alveolar gas is enriched with oxygen and the carbon dioxide produced in the tissues flows from the body to become a part of the external atmosphere. In the marine forms we noted a specialized area of tissue which could be called an oxygen sensor and which informed the organism of the status of oxygen tension in the water; the carbon dioxide sensor is unimportant, if it exists at all. In the mammals the situation is quite reversed, for here we find the oxygen sensor is now relegated to the position of being a vestigal organ and is virtually non-functional. We find also that in the brain (medulla oblongata) is found an area richly perfused with arterial blood and which is exquisitely sensitive to the level of carbon dioxide dissolved in the blood. One could say that the body now has great concern for the level of carbon dioxide in the blood stream and that if pulmonary ventilation is adequate for the removal of carbon dioxide, such ventilation would automatically provide an adequate oxygen tension in the alveolar air. If we examine the composition of the alveolar air, we find it has a remarkable constancy, there being approximately 100 mm Hg oxygen pressure, 40 mm Hg carbon dioxide pressure, about 573 mm Hg nitrogen pressure and 47 mm Hg vapor pressure. The level of vapor pressure is established because the body temperature is regulated to 37°C. If one begins to exercise, an increase of metabolic rate produces more carbon dioxide in the tissues which is carried to the lungs. When the carbon dioxide tension in the alveolar gas tends to rise in the arterial blood, the respiratory regulatory centers in the brain immediately sense this and through nervous connections to the muscles of the chest and diaphragm increase the pulmonary ventilation, thus reducing concentration of carbon dioxide in the alveolar gas. Figure 1 illustrates the effects of inhalation of increased concentrations of CO_2 on pulmonary ventilation and pulse rate. While the respiratory rate is only moderately increased, the total volume per minute is dramatically increased by the effect on depth of breathing. Increased pulmonary ventilation automatically enriches the alveolar gas with oxygen and only under the most severe conditions of physical exercise does this remarkable system fail to maintain constancy of alveolar gas composition.

We have used this oversimplified discussion to illustrate at least two things: (a) the composition of the alveolar gas remains relatively constant, and (b) for the body to operate within normal limits it is necessary to provide an inspired gas mixture sufficiently rich in oxygen to satisfy the requirements for 100 mm Hg O_2 pressure at the alveolar membrane. We will note in Figure 2 the relationship between oxygen partial pressure in the alveolar air and the saturation or amount of oxygen carried in the blood, bound to the hemoglobin molecule. At 100 mm Hg alveolar pressure, the hemoglobin of the blood is fully saturated, and if the full complement of hemoglobin in the blood is present, each 100 cc's of blood will be transporting approximately 20 cc's of oxygen to the tissues.

We note that the S-shaped oxygen disassociation curve provides the mechanisms for a fast dumping of oxygen at the site of the tissues where the oxygen tension is low as a result of metabolism. After traversing the capillaries of the tissues where metabolic gas exchange takes place, the hemoglobin is now partially depleted in its oxygen supply and the blood has picked up carbon dioxide to be transported to the lung and disposed of. It is of interest to note that the venous blood returning to the lung from the tissues normally is approximately 75 percent saturated and contains about 15 cc's of oxygen per each 100 cc's of blood. Thus, at moderate activity levels, each 100 cc's of blood traversing the tissues drops off about 5 cc's of oxygen and picks up incidentally about 5 cc's of carbon dioxide. The relationship between partial pressures of O_2 and CO_2 and amounts transported is illustrated in Figure 3.

EFFECTS OF INHALATION OF INCREASED CARBON DIOXIDE FOR A PERIOD OF 15 MINUTES

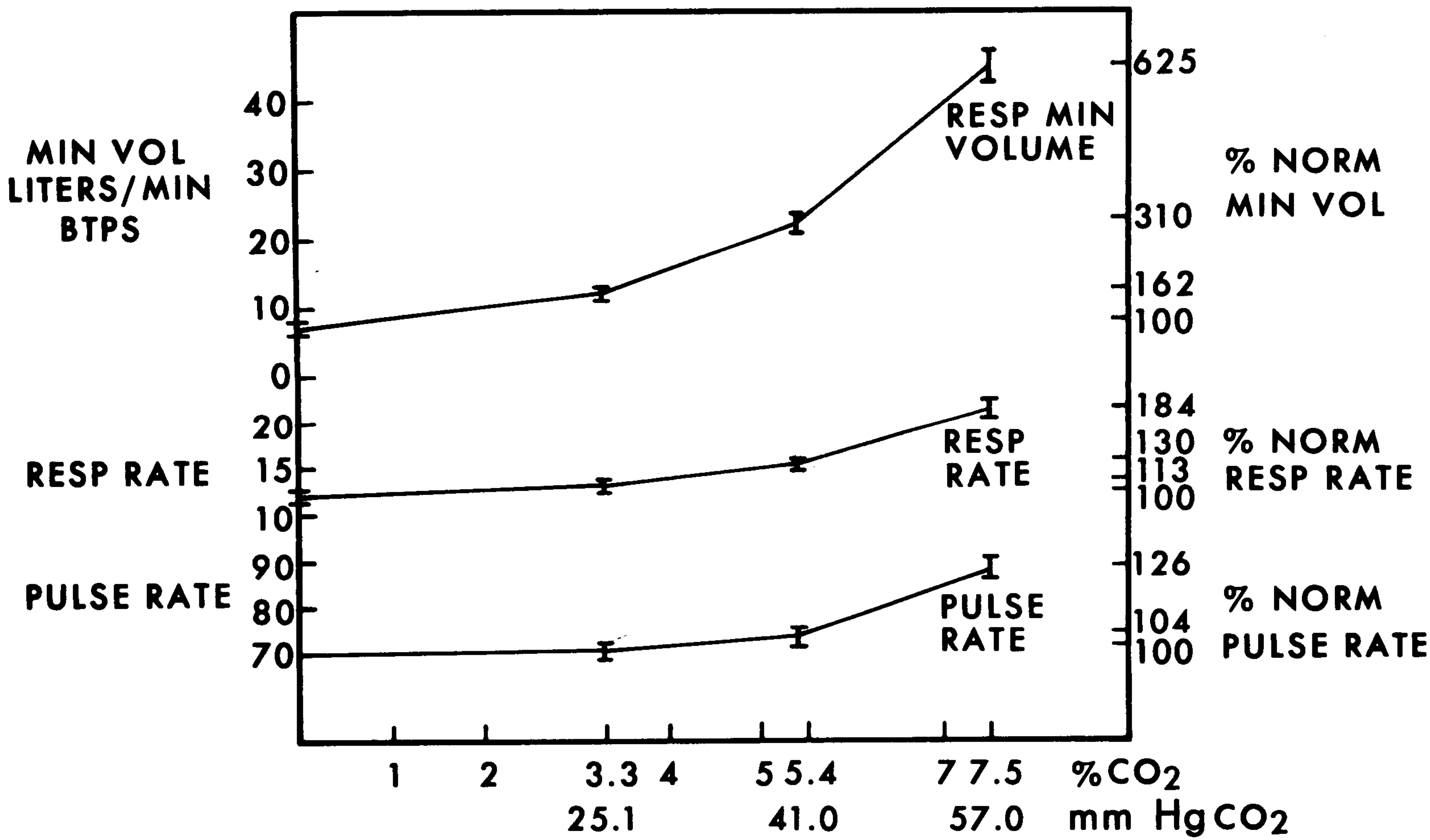


Figure 1

OXYGEN DISSOCIATION CURVES FOR HUMAN BLOOD.

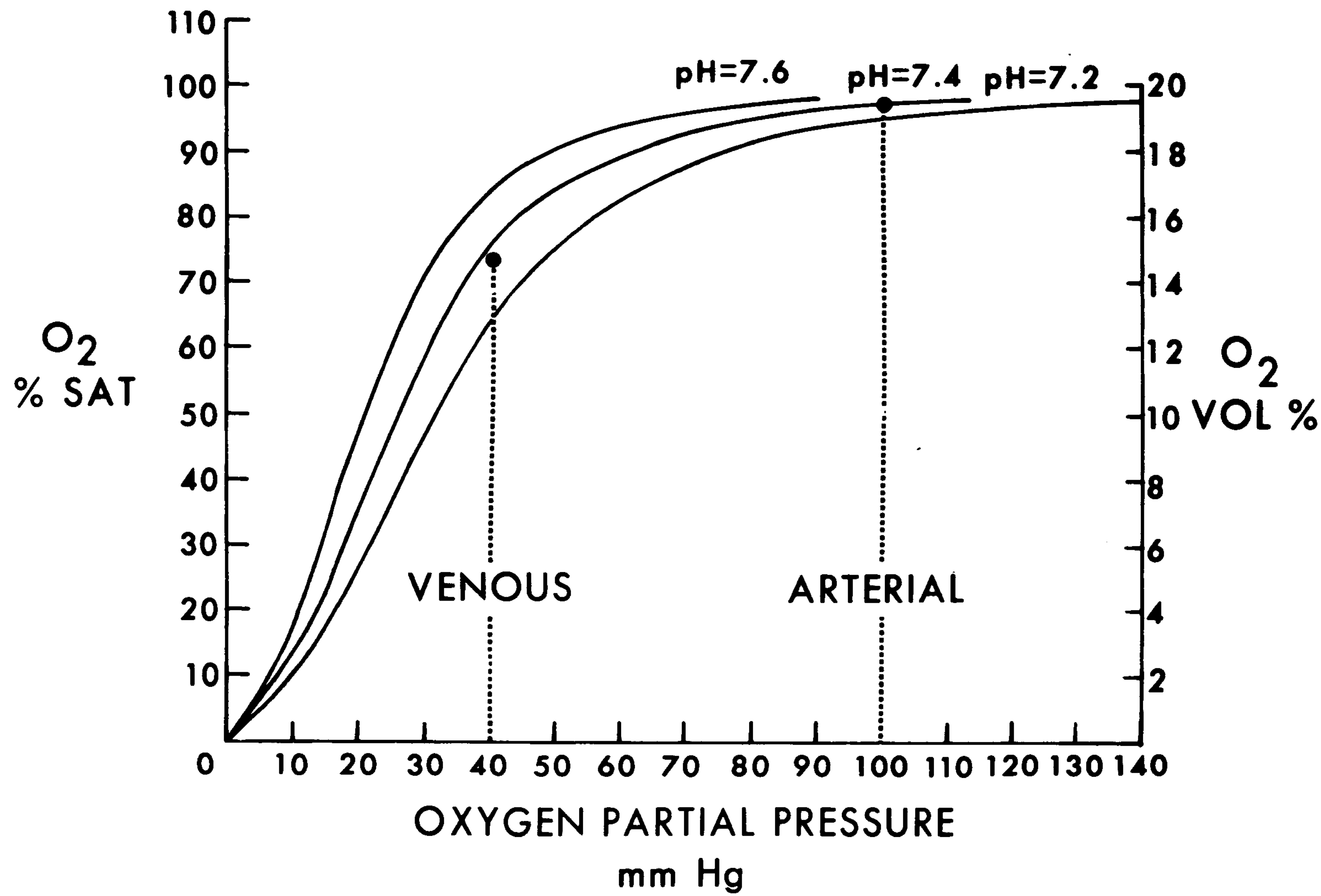
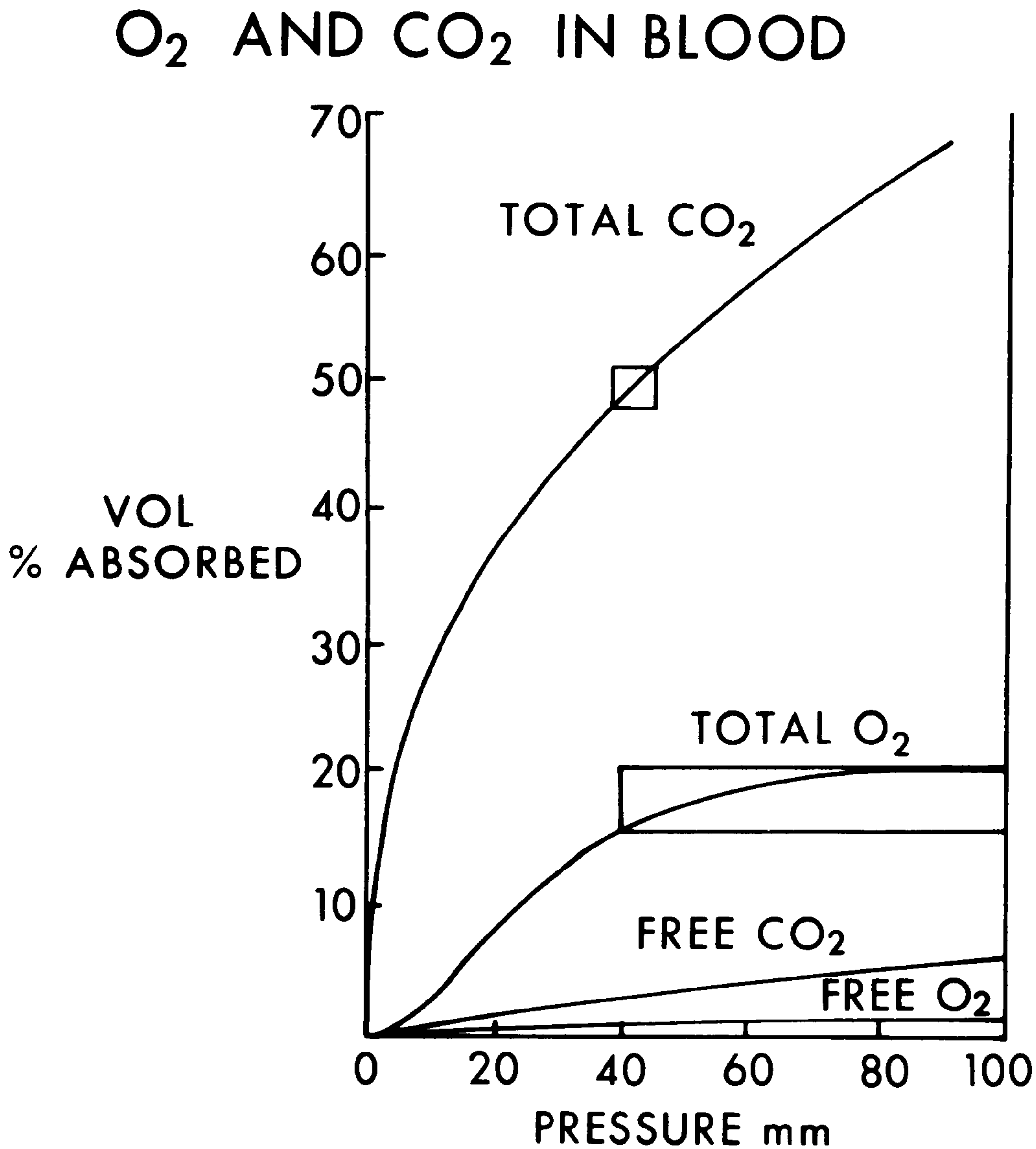


Figure 2



O2 AND CO2 IN BLOOD
VOL
% ABSORBED
70
60
50
40
30
20
10
0
20
40
60
80
100
PRESSURE mm
TOTAL CO2
TOTAL O2
FREE CO2
FREE O2

Figure 3

To illustrate that the layer of air surrounding the earth is really quite thin, one can imagine a circle approximately 40 inches in diameter drawn on a blackboard in which the width of the chalkline represents the relative thickness of the atmosphere. Figure 4 illustrates how the atmospheric pressure decreases as one moves away from the earth. Also are shown curves that depict the changes that occur in the composition of pulmonary gases as the total pressure is decreased. Note that at 50,000 feet (87 mm Hg) the lungs contain only water vapor and carbon dioxide. At 63,000 feet (47 mm Hg) the lungs contain only water vapor, and the phenomenon of ebullience (boiling) takes place.

The fact that oxygenation of the arterial blood rapidly decreases as the pressure of oxygen in the alveolar air is decreased suggests that impaired function of the nervous system will occur at some point as the process of hypoxia (lack of oxygen) progresses. The first effects are impaired vision, then impaired judgment (a sense of exhiliration may exist which may give the victim a false sense of security). As more severe hypoxia occurs, the victim may lose muscular coordination, very similar to alcoholic intoxication. When the oxygen tension in the alveolar air falls to approximately 30 to 40 mm Hg, the arterial blood bathing the brain is sufficiently unsaturated to lead to unconsciousness.

If a person is suddenly exposed to very low oxygen tensions sufficient to cause loss of consciousness, the time between the sudden exposure and the loss of consciousness is approximately the time required for blood previously oxygenated to be pumped to the brain, or about 10 to 15 seconds. Figure 5 illustrates results of experiments in which human subjects were exposed suddenly (rapid decompressions in the altitude chamber) and their time of consciousness measured. It is readily seen that consciousness time in subjects exposed to very high altitudes while breathing air is remarkably shorter than in the subjects who had been breathing oxygen before the decompressions. But the curves come together at about the altitude where the total pressure permits only carbon dioxide and water vapor to occupy the alveolar spaces.

It is apparent that if man is going to travel in space, he must provide oxygen sufficient to maintain 100 mm Hg alveolar pressure, and there must be provision for disposing of the carbon dioxide produced as a result of metabolism. The selection of a spacecraft atmosphere is fraught with many constraints. Obviously the best atmosphere might appear to be air, at one atmosphere pressure; namely, 760 mm Hg. To maintain a pressure of 760 mm in the spacecraft implies a heavier

BREATHING AIR

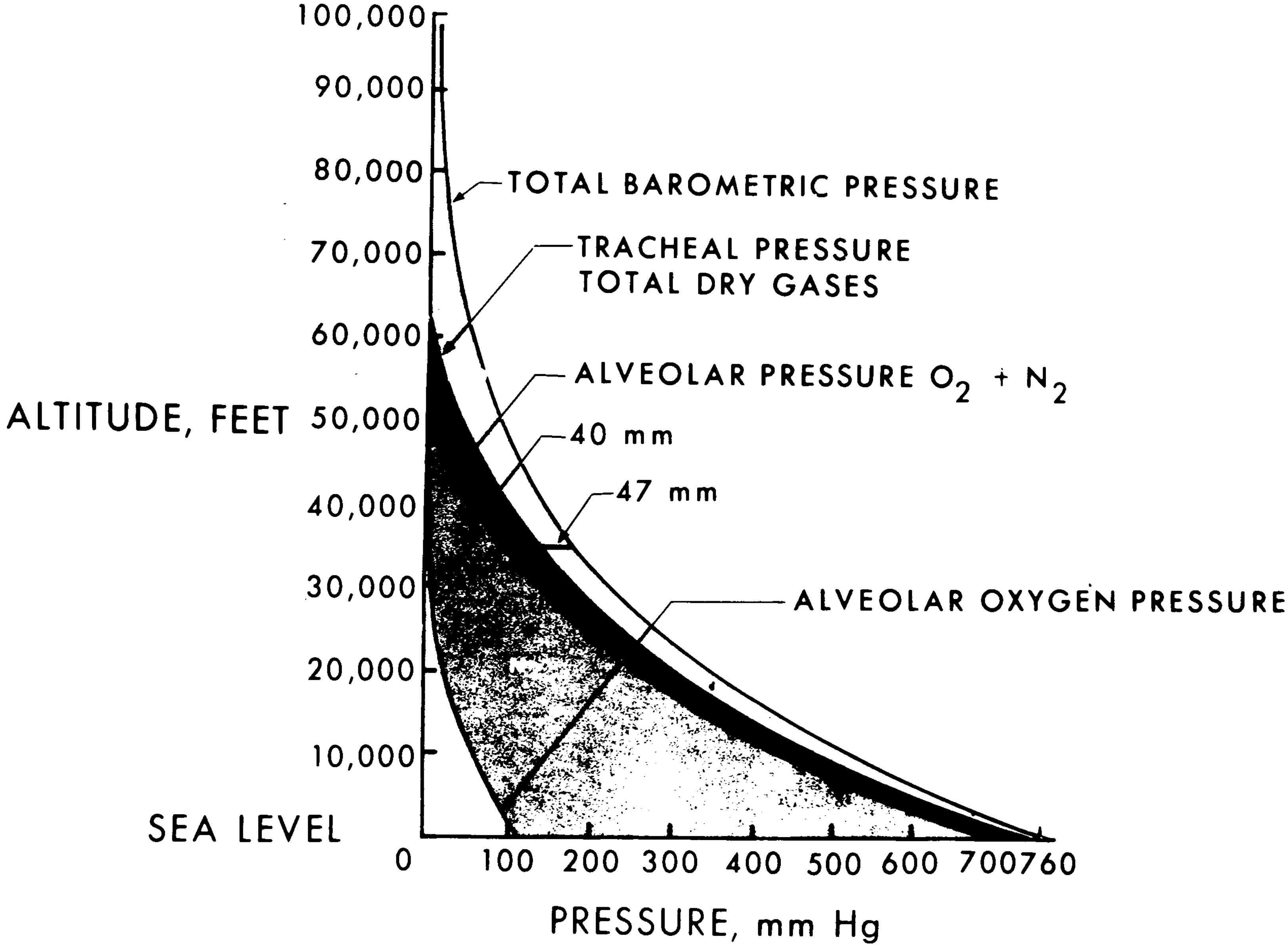


Figure 4

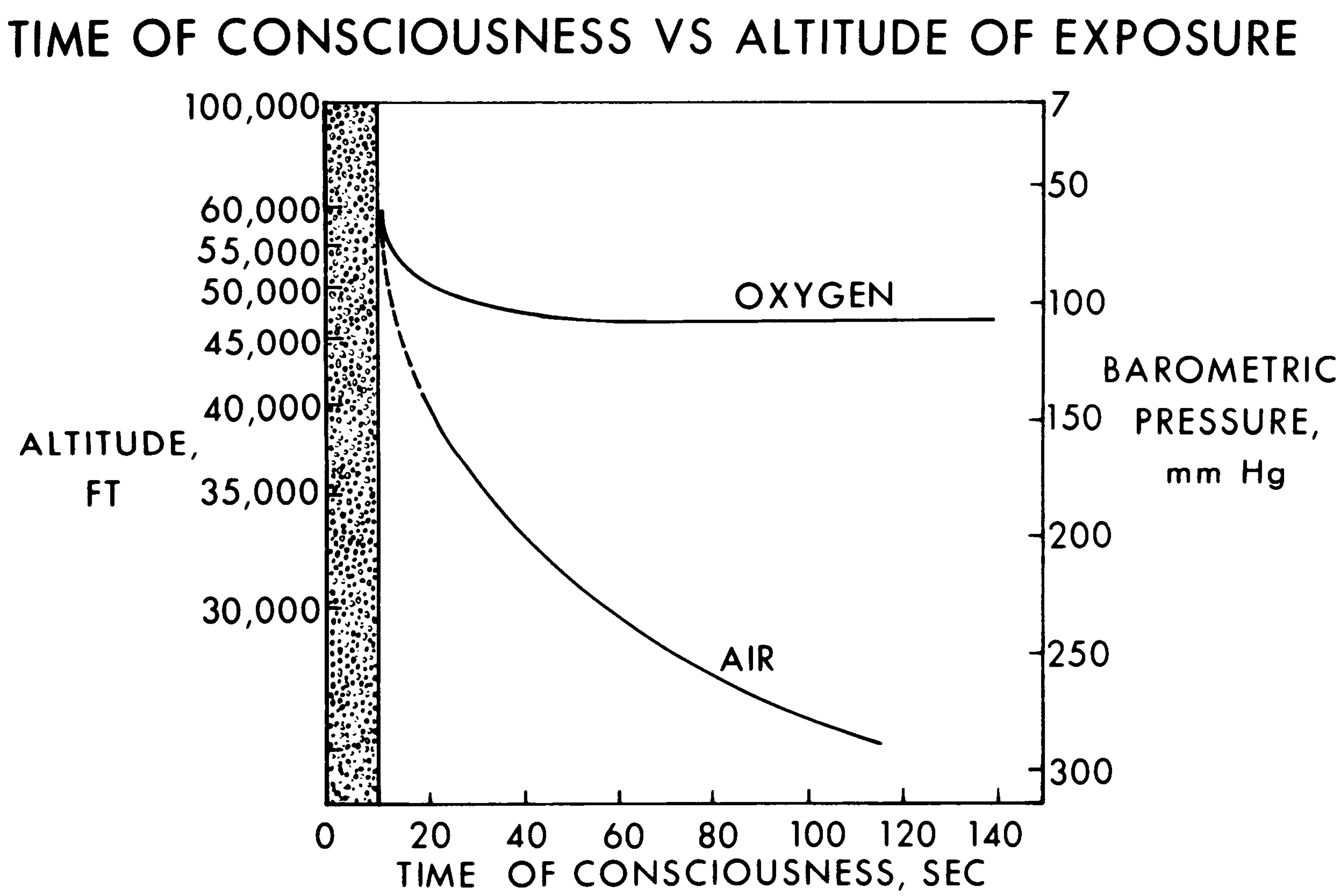

TIME OF CONSCIOUSNESS VS ALTITUDE OF EXPOSURE
ALTITUDE, FT
100,000
60,000
55,000
50,000
45,000
40,000
35,000
30,000
OXYGEN
AIR
BAROMETRIC PRESSURE, mm Hg
7
50
100
150
200
250
300
0
20
40
60
80
100
120
140
TIME OF CONSCIOUSNESS, SEC

Figure 5

walled pressured vessel and a higher risk from leakage at the pressure seals. Although not a subject of this discussion, it is well to mention here another important factor when evaluating the usefulness of air of the spacecraft atmosphere. This factor pertains to the high risk of nitrogen bubble formation in the tissues (aeroembolism), should the spacecraft decompress. The occupants would then rely on their pressurized suits, but would be exposed to an equivalent pressure altitude of about 35,000 feet.

The development of the diluter-demand oxygen regulator during World War II was based upon the fact that as a pilot flies to increasingly higher altitudes, adequate alveolar oxygen tension may be maintained by systematically varying the relative concentrations of oxygen and nitrogen as the altitude increases. The typical diluter demand regulator used in aviation utilizes an aneroid actuated mechanism to close off the air inlet port as the barometric pressure around the regulator decreases, thus increasing the relative amount of oxygen delivered to the mask. Figure 6 is similar to Figure 4 except that the pulmonary gas compositions result when the individual breathes oxygen, rather than air. It is apparent that at an altitude of approximately 34,000 feet (3.6 psia), it is necessary to provide 100 percent oxygen. At that altitude the total pressure is 187 mm Hg. But of that total pressure 47 mm is obligated to water vapor because of the 37°C body temperature, 40 mm is obligated for carbon dioxide because this pressure is required as part of the regulatory mechanism for respiration, 100 mm Hg oxygen pressure is available to saturate the blood. Why not fly with a total cabin pressure of 3.6 psi with pure oxygen? The answer is that this would be a perfectly acceptable cabin pressure, and the fact that both Mercury and Gemini have flown with a 5 psi 100 percent oxygen atmosphere, implies that in the trade-off studies that were used in selecting this atmosphere, consideration was given to the matter of providing some safety factor to the pilots as well as other engineering factors relating to thermal properties of the gas, fan power, etc.

When 100 percent oxygen at reduced pressure was first considered as a possible spacecraft atmosphere, there was some concern that the absence of an inert gas in the lung might set the stage for a pathological condition known as atelectasis. Atelectasis means virtually a collapse of the alveolae in a portion of the lung, and impaired aeration of the blood. When an alveolar space contains only oxygen and carbon dioxide with its associated water vapor and no inert gas, atelectasis might occur if the bronchial tubes leading to the alveolar

BREATHING 100% O_2

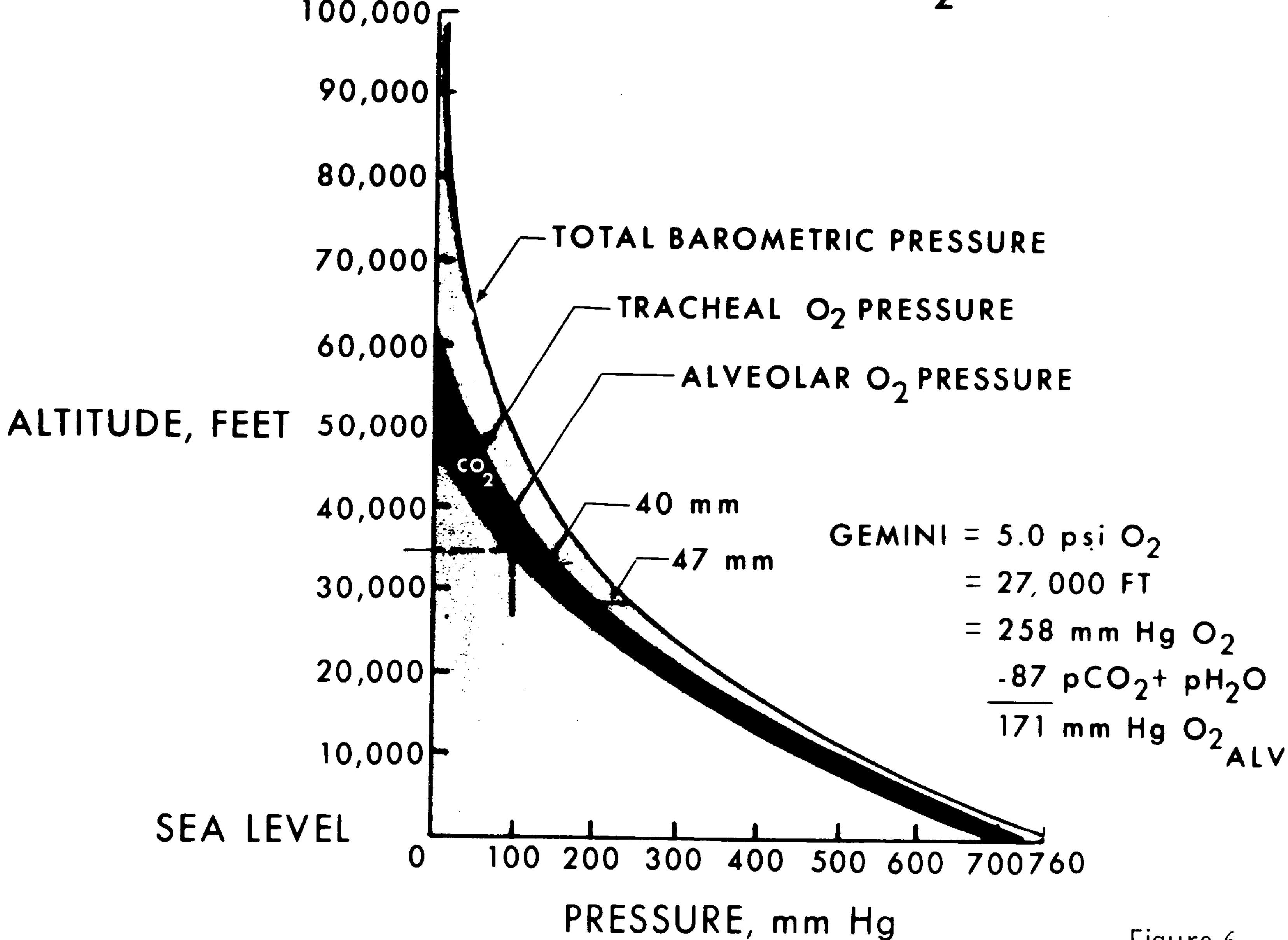


Figure 6

spaces became compressed or clogged from secretions in the lung. The collapse occurs as a result of the rapid adsorption of oxygen from the space, the surface tension of the wetted walls of the alveolar space tend to bring about collapse. This condition is most likely to occur when the lung is subjected to high accelerative forces, i.e., during launch and reentry when the delicate structures of the lungs are displaced in the thorax. At that time bronchiolar collapse may occur with a subsequent collapse of the alveolar cavities. Although there have been a few instances where atelectasis has occurred in persons riding contrifuges and even when breathing pure oxygen for long periods of time in altitude chambers, there is no evidence that atelectasis formation is a hazard in spacecraft at the present time. Considerable confidence exists for the use of the 5 psi 100 percent oxygen atmosphere, and this atmosphere has been used in the Apollo program.

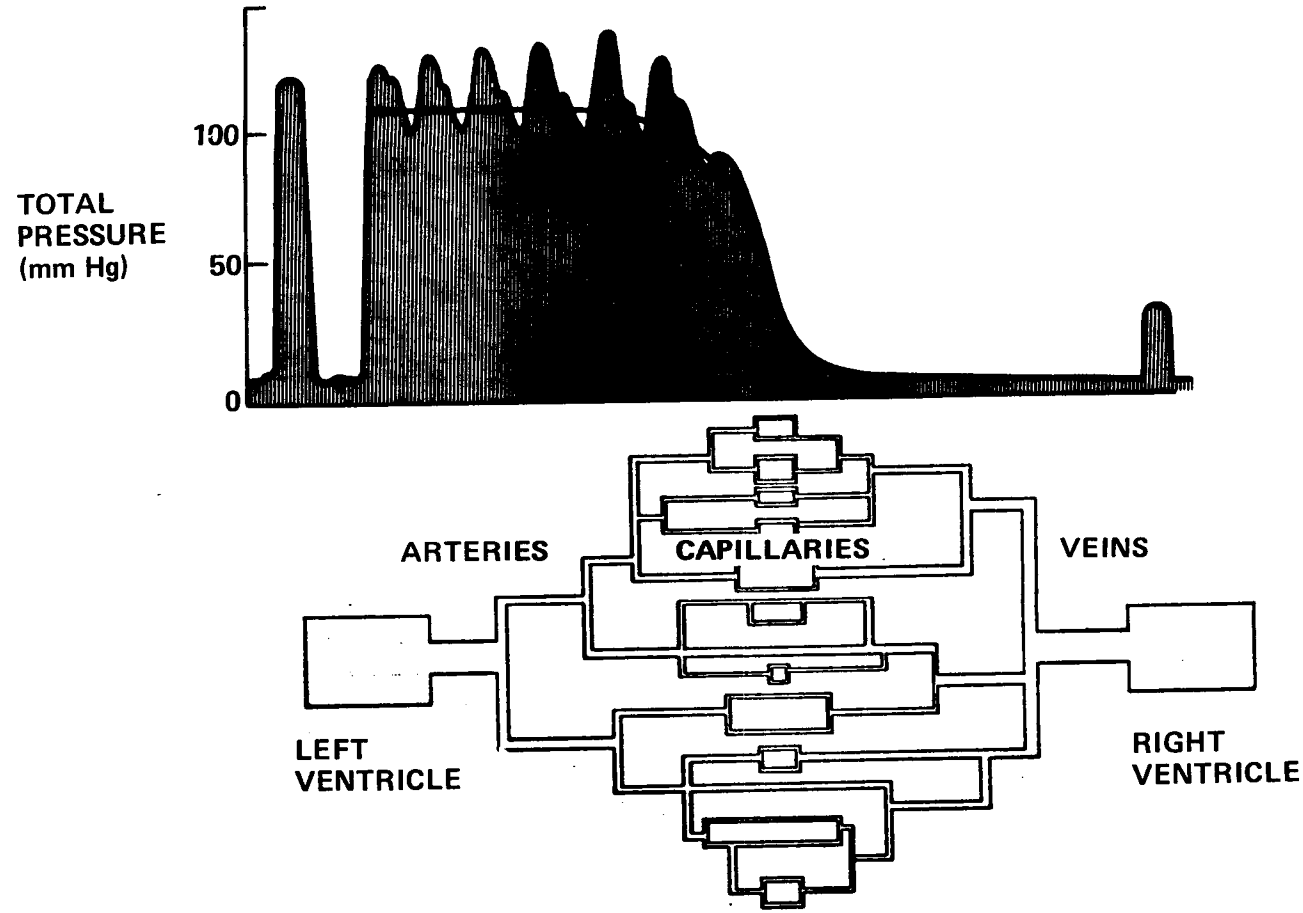
There are manned space flights programmed beyond Apollo, and the durations of these Skylab Program flights will far exceed the two weeks or so that we have or will experience in the Gemini and Apollo programs. Research is constantly underway to evaluate a suitable spacecraft atmosphere for flights of 100 days or longer. It is generally agreed that flights of 30 days may be accomplished without risk using pure oxygen and a pressure of approximately 5 psi. As spacecraft technology improves, there is growing enthusiasm for the use of a mixed gas atmosphere, in which a certain amount of an inert gas will be included. If a 5 psi total cabin pressure is utilized, the atmosphere requirements may be met by using approximately 70 percent oxygen, 30 percent inert gas. If a pressure higher than 5 psi is utilized, the proportion of oxygen to inert gas may be adjusted, keeping in mind, of course, that after dilution with carbon dioxide and water vapor, the concentration of oxygen in the alveolar air must be at least 100 mm Hg.

WEIGHTLESSNESS AND THE CARDIOVASCULAR SYSTEM

In studying and testing the efficacy of the many systems and subsystems of the spacecraft, required to sustain life processes, nearly all the various environmental conditions that obtain in space can be duplicated or simulated on earth with impressive precision, with but one important exception: that of prolonged weightlessness. To be sure, transient periods of null gravity can be achieved by aircraft flying keplerian trajectories, but these brief periods are of little practical value in the investigation of adaptive physiological mechanisms requiring prolonged periods of exposure to this important variable. Since man has evolved under the influence of a gravity state, one might reasonably hypothesize that certain gravity-dependent or gravity-responsive body systems might be expected to change under the influence of null gravity. One might further postulate that man would, in time, adapt to this new condition of weightlessness. Much research effort has been expended in an attempt to test these hypotheses utilizing normal human subjects under conditions of simulated weightlessness. Such investigations are fraught with difficulty, however, because of the impossibility of precisely simulating weightlessness in a lg environment. Utilizing a more pragmatic approach to the general problem of null gravity and its effects on human body systems, actual inflight experiments and observations have helped in no small way to indicate gross trends in potential problem areas and have served to define more precisely those body systems which appear vulnerable insofar as weightlessness is concerned. As our space flights increase in duration and our experience broadens, the ultimate question of man's adaptability to weightlessness will be answered. Of primary concern, of course, is the question of whether or not some system of artificial gravity must be provided on extended space flights in order to maintain the physiological integrity of the human organisms and to insure his safe return to force fields on earth's reentry. The implications of this question are rather clear: if artificial gravity must be provided on extended space flights, be it as a rotating portion of the vehicle or as an onboard centrifuge, the engineering aspects of the task are made considerably more complex.

Probably the most serious of all the postulated effects of prolonged weightlessness was the disturbance in cardiovascular hemodynamics or circulatory impairment. It is well established that prolonged bedrest, immobilization, or water immersion will induce in the human subject a condition known as postural or orthostatic hypotension, meaning simply a fall in blood pressure on assuming the standing position. There was, therefore, good reason to presume that null gravity would have a similar effect, beginning after the first day or so, and progressing thereafter unless remedial measures were employed to combat this cardiovascular "deconditioning" process.

Figure 7 illustrates the pressure and volumes of blood in the systemic circulation. You will note that on the arterial side; that is to say, the systemic perfusion side of the circulation, the pressures are relatively high, being in the neighborhood of 100 mm Hg in the aorta and large arteries and



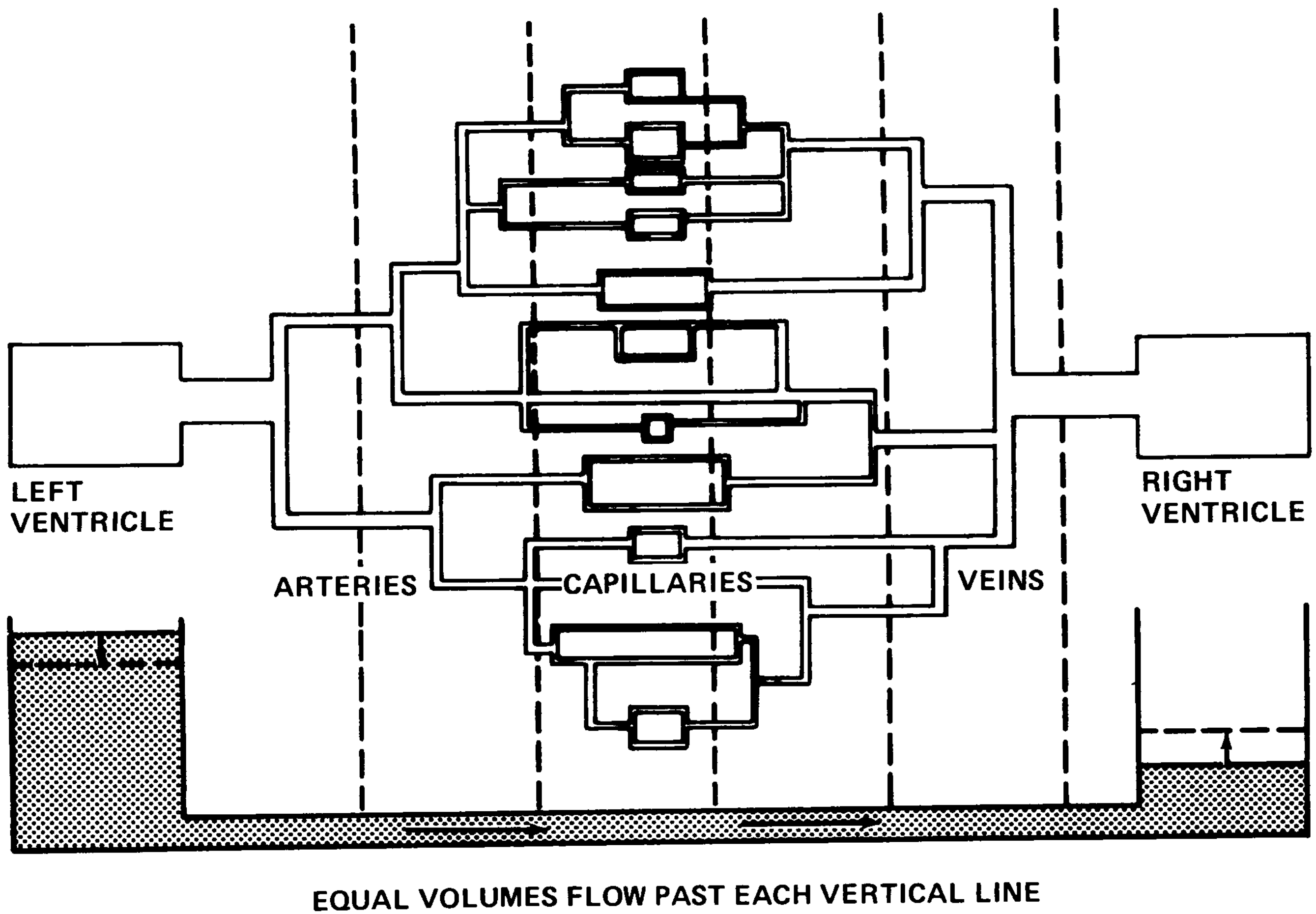
BLOOD VOLUME DISTRIBUTION:

ARTERIES	20%
CAPILLARIES	5%
VEINS	75%

FIGURE 7 - BLOOD VOLUMES AND PRESSURES IN THE SYSTEMIC CIRCULATION
(REDRAWN FROM REFERENCE 26)

falling precipitously as the thin-walled capillaries are perfused. The pressure in the veins becomes nearly atmospheric. The percentage figures indicate the distribution of blood volume between the arteries, capillaries, and veins. A relatively small amount of the blood is in the arteries, and this small amount of blood is under relatively high pressure. The total surface area of the capillaries is tremendously large by virtue of their very large numbers, but the amount of blood in the capillaries at any instant is very small. The veins serve as a collecting reservoir, and account for approximately three-fourths of the total blood volume of the body. In order for the cardiovascular system to perform its functions as a closed perfusion system, it is necessary that the volume flow rate of the blood returning to the right side of the heart must be equal to the volume flow rate of blood leaving the left ventricle and entering the systemic arteries (Figure 8). Note in Figure 9 that the perfusion pressures in the pulmonary arteries are approximately one-sixth as high as in the systemic arteries. It follows that the volume flow rate of blood leaving the right ventricle to perfuse the lung must be equal to the volume flow rate of blood returning from the lung to the left atrium and subsequently to the left ventricle to be pumped into the aorta.

Much attention has been paid to the structure and function of the systemic arterial system. The relatively high pressures carried in this portion of the vascular system and the high incidence of ruptures in the coronary or cerebral vascular beds lends a certain amount of excitement to the study of the systemic arterial system. Only recently has much attention been paid to the venous system. Relatively few accidents happen in the venous system, and we tend to ignore the importance of this blood reservoir. But remember that 75 percent of the blood is contained in the venous system at any one time and that the walls of these vessels are quite thin and distensible. The walls of the veins are richly endowed with smooth muscles held in a partially sustained state of contraction under control of the nervous system. Under normal circumstances, the sustained (tonic) contraction of the smooth muscles in the walls of the veins adjusts the volume capacity of this system to be less than if the muscles were to relax and allow the walls of the veins to distend. Indeed if it were not for the tonic sustained contraction of the smooth muscles in the walls of the veins, the increased hydrostatic pressure in the dependent portions of the veins would result in considerable distention and pooling of blood when an individual changes from the supine



*REDRAWN FROM REFERENCE 26

FIGURE 8 - VOLUME FLOW THROUGH THE SYSTEMIC CIRCULATION*
(REDRAWN FROM REFERENCE 26)

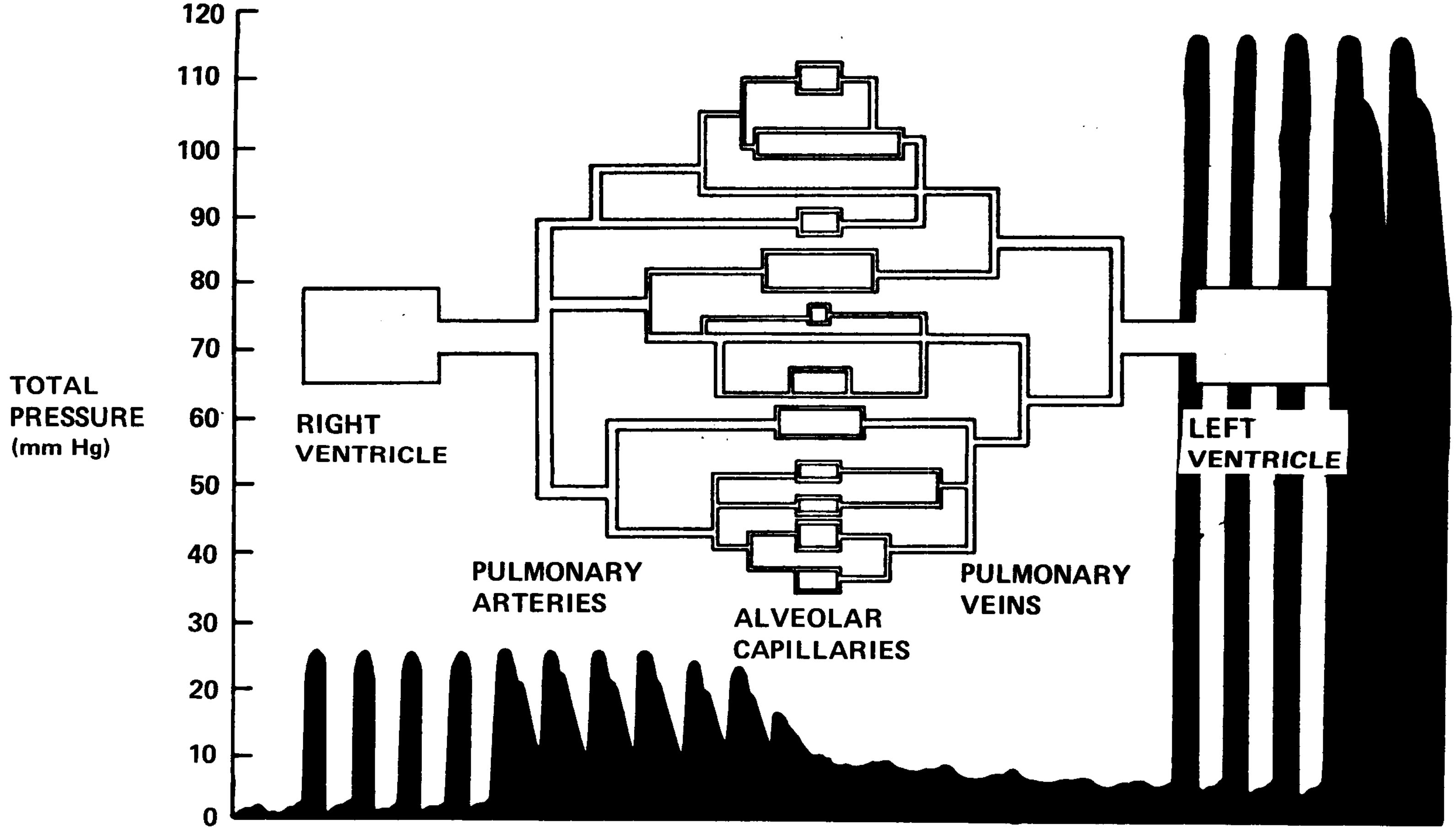


FIGURE 9 - PRESSURES IN THE PULMONARY VASCULAR SYSTEM*
(REDRAWN FROM REFERENCE 26)

to the erect posture. When such pooling occurs, the volume flow rate in the venous system diminishes, and the cardiac output and arterial pressure fall.

In weightless flight there is no hydrostatic pressure difference associated with changes in posture. The rest of this discussion will be devoted to describing the potential physiological responses, particularly in the venous system when weightless flight is undertaken.

THE PROBLEM OF SIMULATING WEIGHTLESSNESS

As stated earlier in this paper, it is not possible to duplicate precisely the weightless condition of space flight in a 1g environment. Each simulation effort falls short of actual duplication. Aircraft flying keplerian trajectories provide only transient intervals of null gravity. Water immersion techniques restrict normal activity and introduce additional variables such as: increased blood volume within the cardiopulmonary vasculatures; "negative pressure breathing"; induced diuresis and probably hypovolemia (reduced effective circulating blood volume). Strict bedrest and cast immobilization techniques do not neutralize all gravitational influences and, in addition, restrict subject mobility. Hence, it becomes very difficult to separate hypogravic effects from those due to restricted body movements.

Since we are constrained to make the best of a difficult situation, it would seem that bedrest is the simulation method of choice, insofar as cardiovascular and musculoskeletal metabolic balance studies are concerned. It is by far the simplest and most technically feasible approach, and minimizes the introduction of additional physiological variables.

CARDIOVASCULAR STUDIES

The heart, essentially a mechanical pump, is dependent upon an adequate return of venous blood in order to maintain cardiac output and a capillary blood volume flow rate sufficient to meet the oxygen requirements of the tissue. In the normal gravity situation, man in the erect position must maintain a positive pressure gradient to insure the flow of blood from the legs to the heart. Opposing the return of blood to the heart is a pressure of some 100 mm Hg, the weight of the hydrostatic column of blood from foot to heart level. Facilitating the return of blood to the heart are the following mechanisms:

a. Massaging of the veins of the extremities by muscular contractions (as in walking), "milks" the blood along, particularly from the superficial to the deeper, more central venous system.

b. A system of one-way valves within the veins also encourages the flow of blood from the superficial veins to the deep venous system, and thence to the heart.

c. The pumping action of normal respiration lowers the intrathoracic pressure from -3 mm Hg on quiet expiration to -9 mm Hg on quiet inspiration, and to values as low as -30 to -40 mm Hg in deep inspiration. This bellows action facilitates the return of blood to the heart by enhancing the necessary favorable pressure gradient.

d. The tone or caliber of the veins themselves aids significantly in facilitating the return of blood to the heart. Contraction of the smooth muscular coat by reflexes mediated through sympathetic nerve fibers decreases the caliber of the veins and decreases the reservoir space available in the venous system for blood pooling or storage, thus encouraging return from the heart.

All these mechanisms are available to aid in venous return to the heart against the opposing hydrostatic pressure of the fluid column. Figure 10 is a much simplified schematic of the various pressures (in millimeters of Mercury absolute) which might be expected in various portions of the vascular tree of man standing in air. On the venous side at the level of the feet, the pressure within the vein is 870 mm absolute, 100 mm of which is derived from the hydrostatic pressure of the vascular column (feet to heart level) and approximately 10 mm of which is residual pressure from the pumping action of the heart.

In these circumstances, the body must utilize all the mechanisms previously mentioned to insure adequate return of blood to the heart. It will be noted that the pressure exerted on the inner walls of the veins at ground level is 100 mm above ambient atmospheric pressure.

If, however, the subject is immersed in water (standing), the schematic in Figure 11 reveals the altered hypothetical pressure levels. In this case, the pressure differential across the venous wall in the foot region is only 13 mm Hg. The pressure exerted on the inner vein wall by the column of blood has been neutralized by the establishment of a similar hydrostatic column external to the body whose pressure is transmitted via the tissues of the leg to the outer vein wall. The same would be true of a subject in the horizontal position during bed rest. The 100 mm hydrostatic pressure of the blood column is reduced to essentially negligible levels. In either case, venous return to the heart is facilitated, and it is presumed that the normally operative venomotor reflexes gradually undergo "functional disuse atrophy", since they are no longer required to help maintain adequate circulation (venous return).

STANDING IN AIR BEFORE IMMERSION

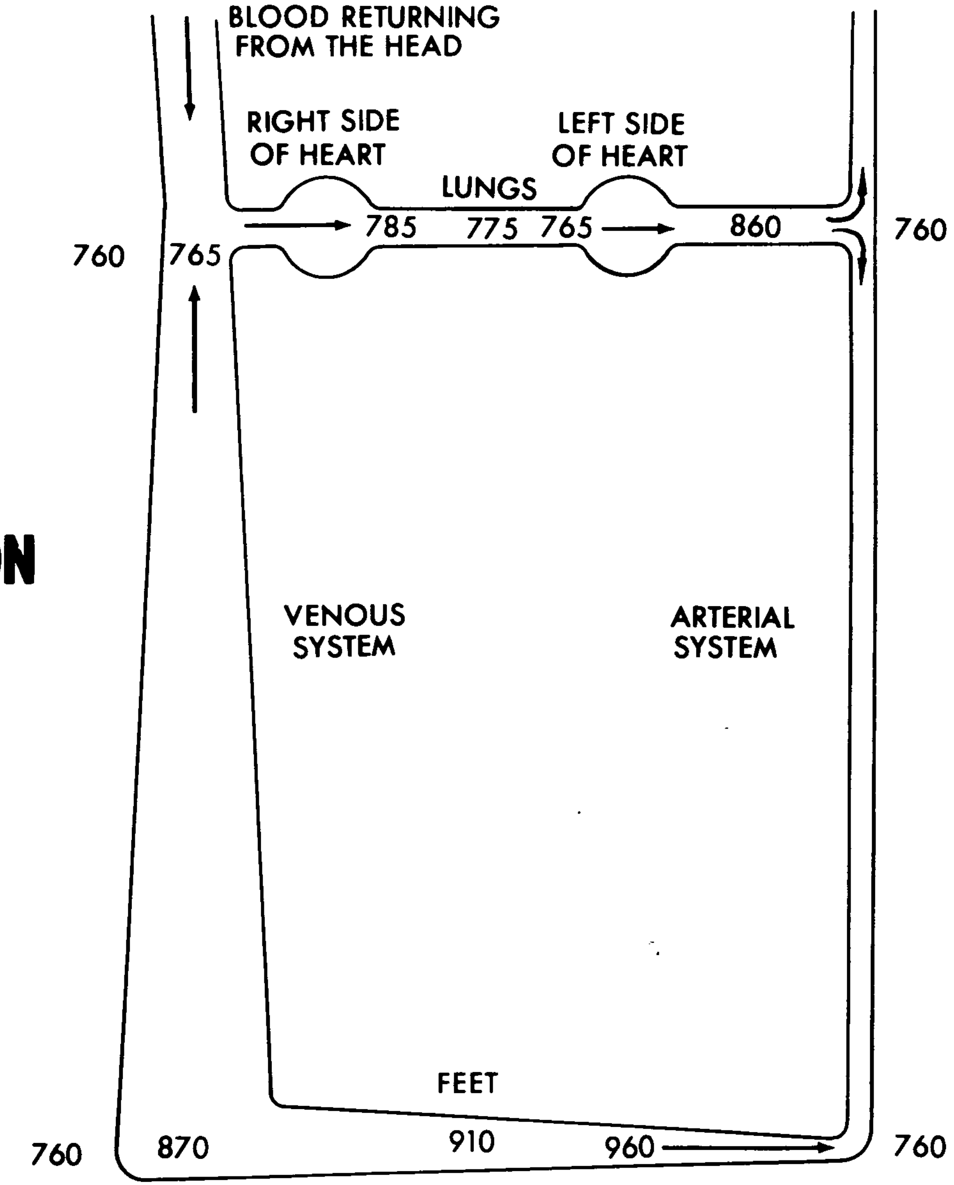


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Figure 10

PRESSURES DURING IMMERSION

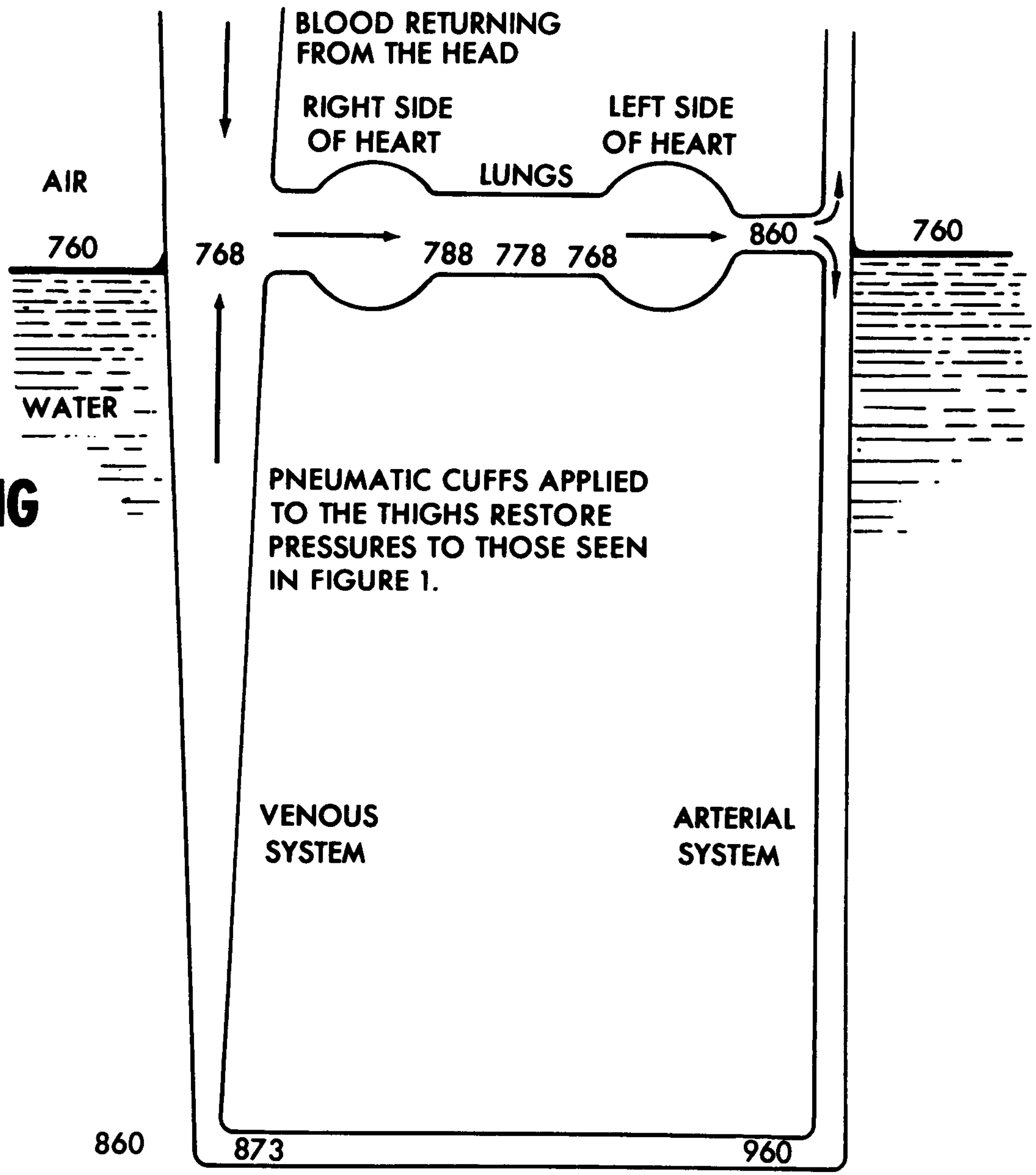

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Figure 11

The functional loss of these peripheral vasomotor reflexes assumes great significance when the subject again stands in air following immersion (or prolonged bedrest). Figure 12 indicates the schematics of this hypothetical situation. Again the weight of the hydrostatic blood column impinges upon the walls of the veins of the legs. But the vasomotor reflexes, sluggish through disuse, are unable to induce contraction of the muscular coat of the veins. The veins then become distended or dilated and permit blood to pool in the extremities. The pressure gradient required for the return of blood to the heart is not maintained, and with diminished venous return, cardiac output decreases, blood flow to and oxygen perfusion of the brain decreases with resultant dizziness or fainting. Syncope or fainting has definite survival value, however, since blood return to the heart is accelerated by the now horizontal position of the subject, and the above process is reversed with the eventual return of consciousness.

But this is a gross oversimplification of the problem, for other factors no doubt are involved. Thus we have barely mentioned the complex changes which occur in the arterial system; the influence of hormonal agents such as the catecholamines, aldosterone, and vasopressin; changes in the physical properties of the blood vessel wall itself; the effects of dehydration, fluid and electrolyte shifts, and hypovolemia. Each of these topics, if adequately discussed, would easily constitute an additional chapter. Suffice it to say that much basic and applied research remains to be done before we will understand the many facets of this problem. In the interim, however, we must take a more pragmatic approach and concentrate on the development of reliable remedial measures to counteract or mitigate the effects of weightlessness on the cardiovascular system.

Prophylactic or Remedial Measures

The prevention of disease or dysfunction is always more acceptable than its therapy, and this applies to the problem of orthostatic intolerance following weightlessness. A simple, practical preventative is the prime objective of much current research activity. Studies have already indicated that physical exercise alone, whether isometric or isotonic, is probably not the complete solution to the problem. Deitrick's studies have shown that pressure applied externally to the lower extremities is an effective remedial measure.

STANDING IN AIR AFTER IMMERSION

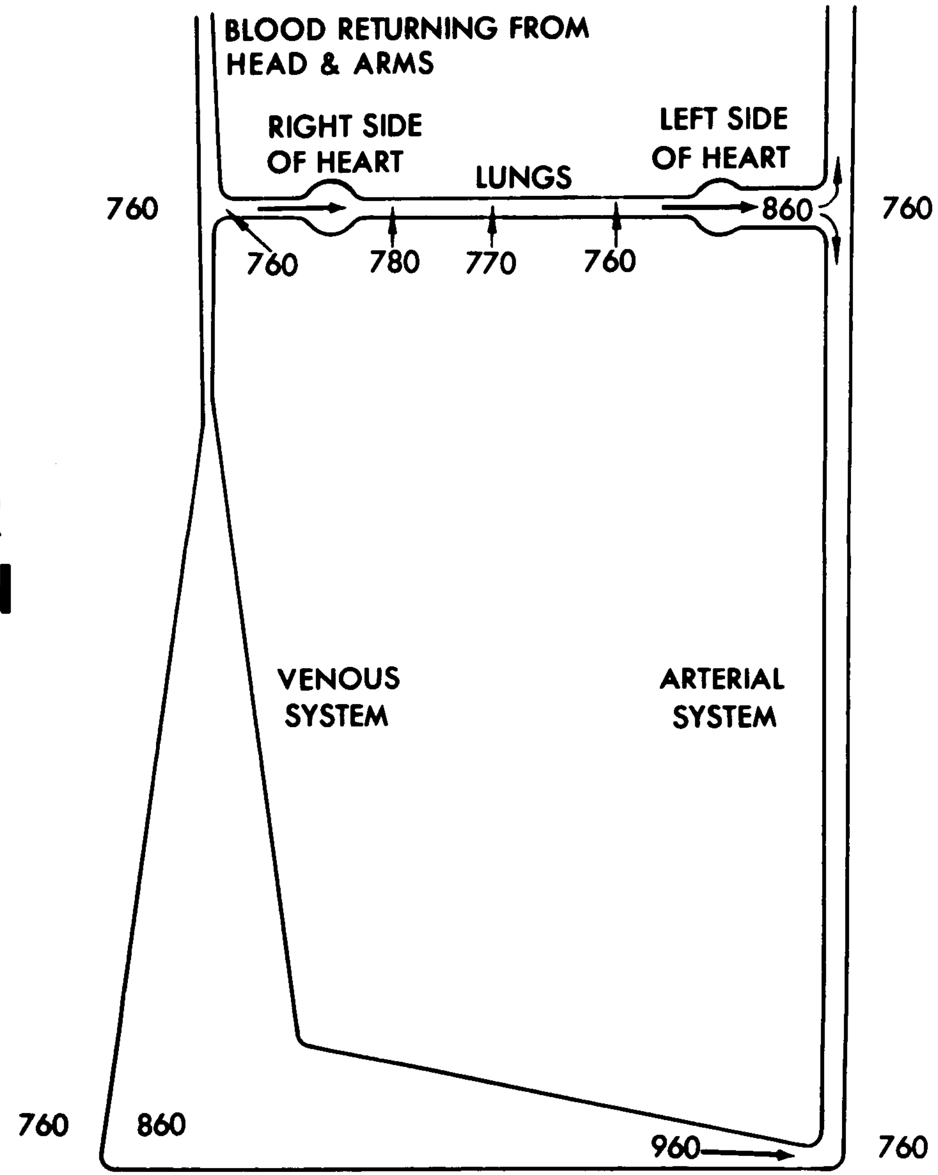

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Figure 12

BLOOD PRESSURE RESPONSES TO TILT-TABLE TESTING

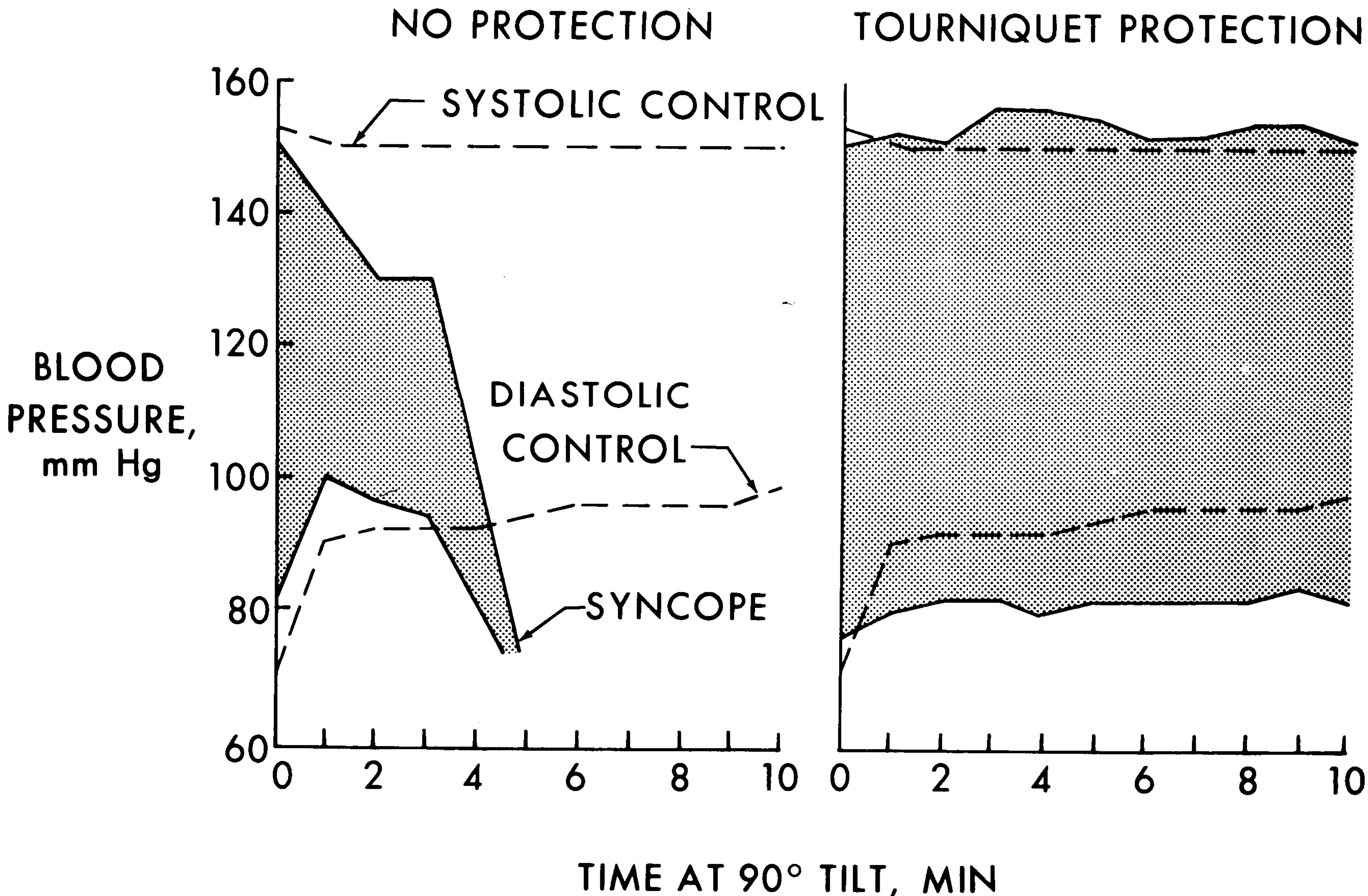

Figure 13

Whedon and his associates have shown that a patient on an oscillating bed will not suffer the marked impairment of vascular reflexes that is observed in other patients on bedrest. The intermittent tilting of the feet several inches lower than the heart provides sufficient gradient of hydrostatic pressure to stimulate the vascular reflexes and thus the patient retains considerable ability to prevent blood pooling when he attempts to stand or walk. Extending this idea, Graveline has proposed that intermittent occlusion of venous return from the arms and legs by means of pressure cuffs inflated to 60 mm Hg might also prevent the loss of vascular reflexes. Tests were conducted on subjects while completely submerged in water, by inflating pressure cuffs on a cycle of 1-minute pressure and 2-minute deflation for a period of 6 hours. Following immersion, orthostatic tolerance was estimated by tilt table testing using a 90° tilt for 10 minutes. The results of tests on one subject are shown in Figure 13. This subject fainted and was removed from the tilt table 5 minutes after beginning the test following submersion for 6 hours. However, the same submersion with cyclical occlusion of venous return from the legs and arms did not produce the loss of vascular reflexes. All subjects tested showed marked improvement of these reflexes following submersion with the use of cyclic venous occlusion.

The ultimate test of any cardiovascular conditioning technique is its ability to maintain the subject's tolerance of reentry accelerations in the face of any body heating and fluid loss (dehydration) which may be expected on a given mission. An alternate approach is the use of antigravity suit, although its incorporation into a space suit is fraught with technical difficulties and might best be avoided if at all possible. It is now planned to investigate the use of elastic leotards or full length elastic stockings or elastic bindings over the legs to be installed prior to reentry. The clinical use of this technique is well established, and it is anticipated that such a therapeutic device might have considerable usefulness.

Still another approach is the use of drugs. Although physical preventative measures are generally preferable to the therapeutic pharmacologic approach, the efficacy of various sympathomimetic drugs and hormonal substances such as vasopressin and aldosterone must be investigated. Aldosterone and desoxycorticosterone acetate (DCA or DOCA) are potent steroids which encourage sodium retention by the kidneys, and therefore are potentially useful, in preventing fluid and electrolyte loss and resultant hypovolemia.

Cardiac Receptors and Fluid Volume Control

Blood volume control involves the interplay of two major variables: the anatomic size of the intravascular space at any particular tension of the smooth muscles in its walls, and the blood volume itself. Since plasma volume is a part of the extracellular fluid which in turn is regulated by the kidney, the problem of blood volume control stands at the intersection of renal and circulatory physiology. Until recently mechanisms which might underlie this control were relatively unexplored. However, during the past 10 to 15 years a number of investigators have found it necessary to postulate the existence of a volume determined control mechanism in order to explain certain aspects of kidney behavior for which they could not otherwise account. The early and classical work in this field of physiology was done by Gauer, Henry, and Sieker. It is well to remember that in weightless flights the absence of hydrostatic pressure differences in the vascular system may and undoubtedly does result in gross disturbances in the distribution of blood volume. As mentioned earlier, this disturbance is most likely to occur on the venous side of the circulation of which a part is the pulmonary circulation, for these two compartments are virtually one. If one reverses the direction of the hydrostatic pressure differential by placing the body in a head down position, it is noted that blood flows from the large venous reservoir into the pulmonary circuit. Thus it is possible to produce compensatory disturbances in blood volume by simply altering the hydrostatic pressure differentials in the body. Gauer and his co-workers became interested in the problem of blood volume regulation and hypothesized that there should be sensing elements throughout the circulation, with an integrating computer in the central nervous system, to sense the fullness of the bloodstream, as it were. They noted further that following transfusion of blood into the vascular system, a water diuresis was performed by the kidney. It is common knowledge that when water intake is diminished, urine output is likewise diminished.

Where would one look for a sensing element to be used in the regulation of blood volume? One must recognize that the arterial blood volume constitutes less than 20 percent of the total blood volume and that the distensibility of the arterial system is only one to two hundredths of that of the rest of the circulation. The arterial pressure is determined dynamically by cardiac output and flow resistance. If the heart misses only two or three beats, the mean pressure falls almost immediately below 30 mm Hg. Yet, because the delta P/delta V of the arterial system is about 1 mm Hg per milliliter, in spite of the precipitous drop of mean pressure no more than 200 ml of blood are transferred from the arterial to the venous side. On the other hand, the pressure in the low pressure system is relatively insensitive to changes of flow resistance and cardiac performance. The delta P/delta V of the venous or capacitance system is in the order of 7 centimeters H_2O per 1,000 ml, and the injection of 200 ml of blood during arrest of the heart will produce a barely measurable pressure increase. This difference in distensibility between the two systems is also responsible for the imbalance of blood distribution following a transfusion: of 1,000 ml injected, 990 to 995 ml will remain in the low pressure system and only 5 to 10 ml will go into the arterial system. These considerations alone imply that volume control is likely to be related to the state of the low pressure system: changes of total blood volume only indirectly entail changes of arterial blood volume and pressure.

By definition, the low pressure system is composed of the capacitance vessels of the greater (systemic) circulation plus the pulmonary circulation and the left ventricle in diastole. The central blood volume proper lying between the pulmonary and aorting valves holds a key position, for it serves as a reservoir enabling the left ventricle to deliver approximately six stroke volumes even when the venous return is completely interrupted.

Experiments have been conducted in which total blood volume has been altered from +30 percent to -30 percent of normal, and under those circumstances occurred parallel changes of pressure in the central veins the pulmonary artery, and the left atrium. Thus the right heart does not appear to act as a barrier between the central venous blood volume and the pulmonary blood volume. The whole system behaves passively like an elastic bag with a well-defined pressure volume relationship. As long as this relationship is undisturbed by a contraction of the vascular wall, any site within the low pressure system, particularly in the highly distensible great vessels and atria, would be well suited to record changes in total blood volume.

The circulatory system by itself is not hermetically sealed, but communicates with the interstitial fluid spaces. Measurements of plasma dilution after a hemorrhage of 500 cc in one experiment revealed that approximately half the volume lost in the hemorrhage was replaced within 20 minutes by interstitial fluid. This means that, in the absence of vasomotor activity of the capacitance vessels and other peripheral vascular beds and as long as the permeability stays within normal limits, the atrial receptors may from their central observation post, not only control total blood volume but also interstitial fluid volume. All measures that lead to an expansion of the central reservoir are accompanied by diuresis, while depletion of this critical area produces oliguria (reduction in urine formation).

It has been demonstrated that continuous positive pressure breathing results in an anti-diuresis in man. Conversely a marked diuresis has been shown to occur during continuous negative pressure breathing of -8 to -10 cm of water. Detailed studies of renal hemodynamics, electolyte, and water excretion indicated that positive and negative pressure breathing while effecting a variety of parameters, primarily influenced water excretion by the kidney. These experiments have led to the hypothesis that induction of alterations of intrathoracic pressure by changes in the ambient breathing pressure effect urine flow primarily through an increase or decrease in antidiuretic hormone activity. The picture is somewhat complicated by the fact that alterations in intrathoracic pressure alter the resistance to blood flow through the pulmonary circuit and thus alter the cardiac output. But it can be concluded that positive pressure breathing decreases both the cardiac output and the central blood volume; negative pressure breathing, on the other hand, increases the cardiac output without measurably affecting the central blood volume.

The foregoing evidence suggests that the probable cause of the changes in urine flow induced by negative and positive pressure breathing is the increased or decreased stimulus to volume receptors resulting from the congestion or loss of blood from the thoracic circulation. An interesting experiment was performed, in which a small rubber balloon was introduced into the left atrium of an anesthesized dog. When this balloon was distended by injecting water into it to produce a graded obstruction at the mitral orifice, a rise of pressure in the left atrium and pulmonary intervascular volume was observed. In 37 such balloon distentions in 13 dogs, in spite of the obstruction to the circulation, there was in all but 4 cases an increase in urine flow which in 14 trials was two to fivefold. One such experiment is illustrated in Figure 14. BI indicates "balloon inflation."

These results narrowed down the possible sensitive regions and pointed to a physiologic role for left atrial receptors. Although the left atrium could not be distended separately, the experiment showed that engorgement of the pulmonary vascular bed was effective only if the left atrium was included in the congested area.

Receptors and Afferent Pathways

The vagus nerves form connections between the heart and the brain. Impulses passing from the brain to the heart influence the rate at which the heart beats. But the vagus nerves are rich in connections which transmit signals from the heart to the brain. Neurophysiologists have actually detected afferent

RESPONSE TO DISTENTION OF A LEFT ATRIAL BALLOON

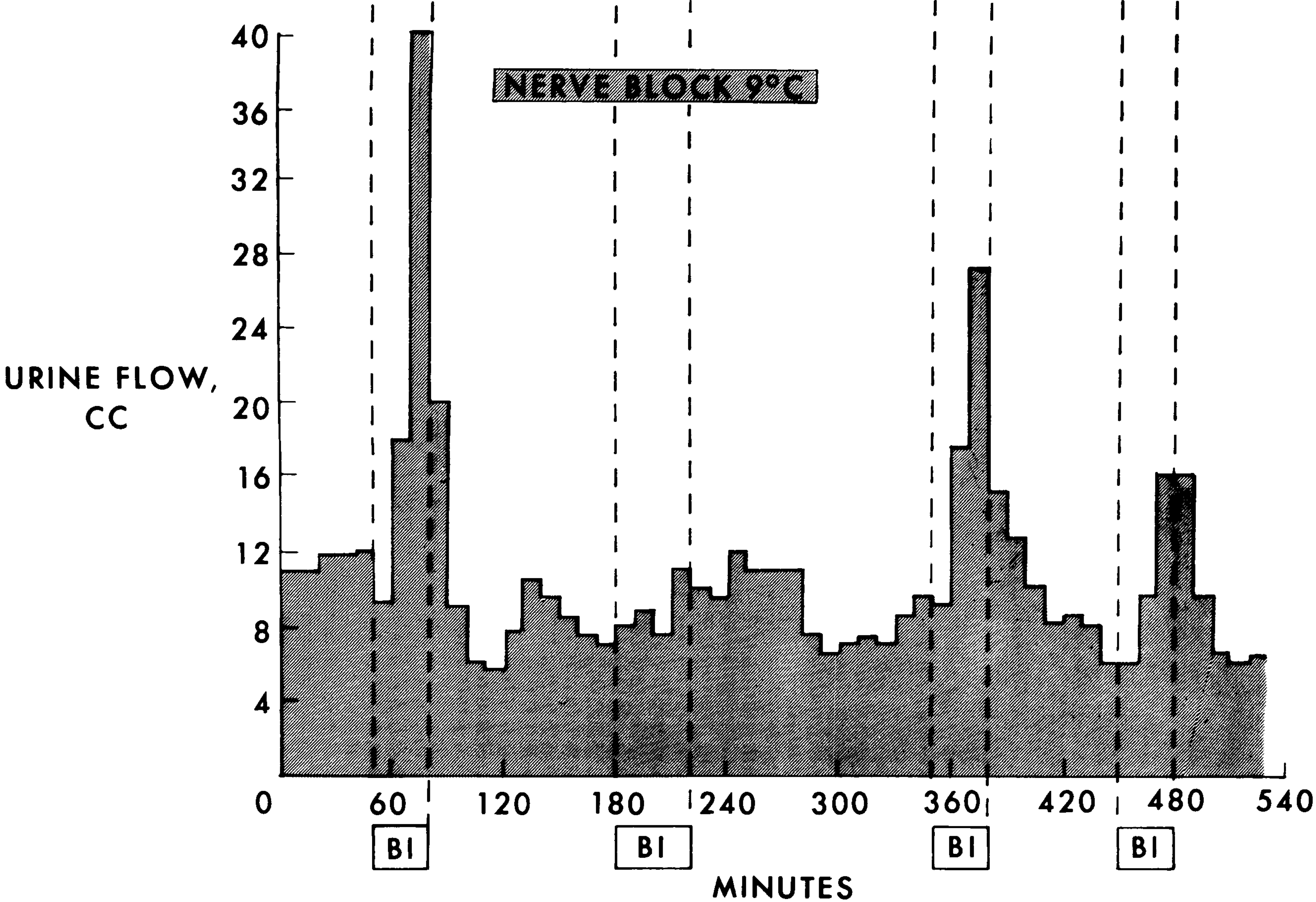

Figure 14

signals on nerve fibers in the vagus nerve from the heart which they interpret as signalling pressure changes in the atria. It has been pointed out earlier that these were the most distensible reasons in the cardiovascular system and hence the most effective "observation posts" for the sensors of a volume regulatory mechanism. When the vagus nerve was cooled to 8°C, (see Figure 14), the nervous pathways involved were interrupted and the response to negative pressure breathing and to balloon distention was abolished. When certain single nerve fibers were dissected from the main trunk of the vagus nerves, it was found that a change in activity on the nerve was found in all those circumstances in which intrathoracic blood volume was changed. Thus the removal of 50 cc's from a 10 kg dog led to a significant reduction in atrial fiber activity. Infusions had the reverse effect. The increase in activity noted with negative pressure breathing was modest but when an atrial balloon was distended it was marked.

One disturbing fact enters the picture, however, and that is that during congestive heart failure there may be retention of water and sodium despite extreme atrial distention. However, it is now believed that during congestive heart failure, the normal pulsatile stretch of the atria is abolished, and it is believed that it is the pulsatile nature of the stimulus that succeeds in generating impulses indicating increased volume of blood in the thoracic circulation. Without elaborating upon all the experimental evidence to date, suffice it to say that the current theory of blood volume regulation implicates at least the left atrium as the site of the sensor acting through the vagus nerve to the hypothalamus of the brain. There is caused to be liberated by the posterior pituitary varying amounts of antidiuretic hormone to be carried by the bloodstream to the kidney where the diuretic or antidiuretic effect is elaborated. In short, when the balloon is inflated in the left atrium, the presence of antidiuretic hormone in the serum is reduced.

Are these relatively recent observations pertinent to the study of blood volume regulation in space flight? We believe they are, because in weightless flight the stage is set for loss of venous tone through lack of normal hydrostatic pressure gradients and the associated stimulus to the nervous activity in the muscles of the vein walls. Additionally, the shift in blood volumes, favoring a relative engorgement of the thoracic circulation may account for stimulation of volume sensors and loss of a portion of the blood water volume via the kidney.

Dehydration and loss of venous tone together favor orthostatic intolerance upon return to the 1g environment.

THE PROPRIOCEPTOR SENSATIONS: KINESTHESIA, MUSCLE SENSE, AND EQUILIBRIUM

Proprioception means "position sense." The proprioceptor sensory organs apprise the nervous systems of physical states, including (1) the movement of joints, (2) the positions of joints, (3) tensions of muscles, (4) the tensions on tendons, and (5) the orientation of the body with respect to the pull of gravity or other acceleratory forces. The sensations from the joints, muscles, and tendons are all somatic (body) sensations and have certain characteristics in common with the other peripheral sensations which include sight, hearing and touch. The vestibular sensations, which detect the pull of gravity and the forces of acceleration, originate in the vestibular apparatuses which transmit impulses to the brain via the vestibular portions of the eighth cranial nerve, which also carries impulses from the cochlea (organ for detection of sound vibrations).

Kinesthetic Sensations

The term "kinesthesia" means conscious recognition of the orientation of the different parts of the body with respect to each other as well as of the rates of movement of the different parts of the body. These functions are subserved principally by extensive sensory endings in the joint capsules and ligaments.

The Kinesthetic Receptors

Three major types of nerve endings have been described in the joint capsules and ligaments about the joints. By far the most abundant of these originate from end organs (you may call them transducers, if you wish) which are stimulated strongly when the joint is suddenly moved. Another type, a stretch receptor, is found particularly in the ligaments about the joints. They also respond when the joint is suddenly moved. A third type of end organ is also found in the tissues around joints, and presumably detect the rate of movement of the joint. A different set of joint receptors is stimulated by different degrees of angulation of the joint. For instance, if the forearm is flexed, one set of receptors will be stimulated; whereas another set will be stimulated when the forearm is fully extended. At intermediate points between these two extremes, still additional sets of receptors are stimulated. The information from these joint receptors continually apprise the central nervous system of the momentary position of the joint. These same receptors are stimulated to a still greater extent during actual moving at the joint. Thus, the necessary kinesthetic information for detection of joint movement is also transmitted into the central nervous system.

Muscle and Tendon Sensations

The muscle and tendon sensations, sometimes called muscle sense, are concerned with (a) the degrees of contractions of the muscles, (b) the degrees of stretch of the muscles, and (c) the amounts of tension on the tendons. These sensations function either entirely or almost entirely subconsciously, for electrophysiological studies have failed to demonstrate transmission of any signals from the muscle proprioceptors to the conscious areas of the brain. Yet, tremendous amounts of information are transmitted from the muscles and tendons to (a) the spinal cord, and (b) the cerebellum to cause reflexes associated with equilibrium, posture, and "damping" of movements. The two types of sensory organs responsible for muscle and tendon sensations are the muscle spindle and the Golgi tendon apparatus. The muscle spindle is located within the muscle itself, and consists of a bundle of 2 to 10 thin specialized muscle fibers (intrafusal) surrounded by a connective tissue capsule which attaches at its ends to the connective tissue fibers which form the structural framework around all contractile muscle fibers comprising the muscle mass. Thus, in a muscle such as the biceps of the arms, many thousands of long and contractile individual muscle fibers are found. They are held together in a series-parallel arrangement and when stimulated by the motor nerves to the biceps muscle cause shortening of the muscle mass. From its anchor point near the shoulder, the biceps acts upon the articulation of the elbow joint causing flexion of the lower arm. But interspersed throughout the muscle mass are the specialized muscle fibers brought together in a special capsule surrounded by connective tissue. The muscle fibers that comprise the muscle spindle do not contribute to the strength of the whole skeletal muscle but serve rather as sensory organs, or transducers, to provide information to the central nervous system on the position of the articulated skeletal structure to which it is attached as well as the force against which the skeletal muscle is acting. The intrafusal muscle fibers of the spindle are innervated by nerve fibers distinct from those larger fibers which originate from the motor areas of the spinal cord to stimulate the extrafusal skeletal muscle fibers. Thus, a neuromechanism exists to make it possible for the intrafusal muscle fibers within the spindle to contract independently of the muscle fibers which comprise the whole skeletal muscle. See Figure 15.

THE MUSCLE SPINDLE

A. MOTOR (EXCITATORY) NERVE FIBERS TO INTRAFUSAL MUSCLE CELLS

B. SENSORY NERVE FIBERS WHICH SENSE TENSION (ANNULOSPIRAL NERVE ENDINGS)

C. MOTOR (EXCITATORY) NERVE FIBERS TO EXTRAFUSAL MUSCLE CELLS

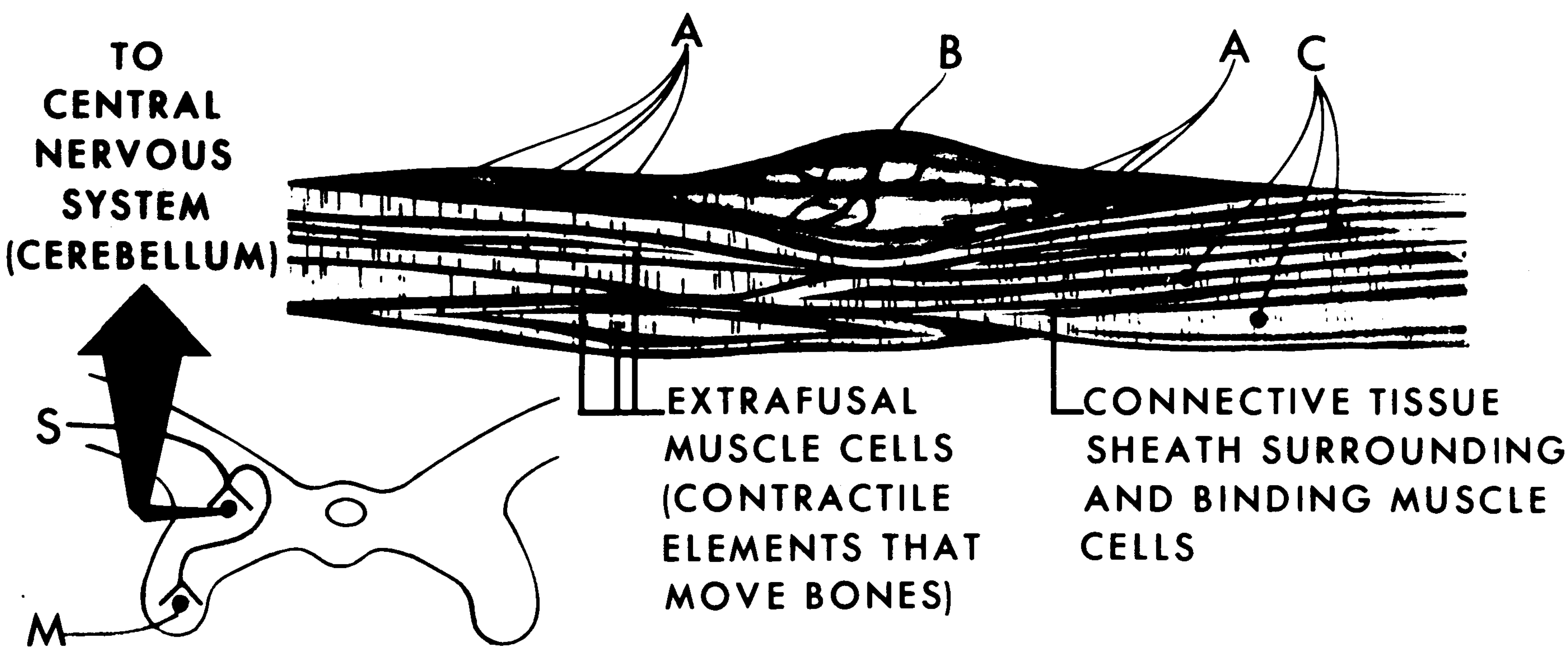

Figure 15

Within the muscle spindle and entwined around the central area is a network of nerves called the annulospiral endings. Nervous connections from this area pass into the spinal cord and enter the sensory portion of the nervous system. It would be well to point out here that the specialized muscle fibers found within the muscle spindle have retained the ability to contract only at the ends of the muscle fibers and the central portions around which are found the annulospiral endings of the sensory nerves have lost their ability to contract. Thus when the muscle fibers within the spindle are caused to contract, the end portions alone contract and actually stretch the central portion of the spindle.

Stimulation of the Muscle Spindles

The muscle spindle can be stimulated in either of the following two ways: (1) it can be stimulated by stretch of the entire muscle belly; that is to say, the whole muscle mass which also stretches the muscle spindle, and (2) it can be stimulated by contraction of the intrafusal fibers of the spindle (shown as A in Figure 15), which contracts the two ends of the spindle but stretches the middle. In other words, the stimulus which normally excites the muscle spindle, is the stretch of its middle portion whether this is caused by stretching of the entire muscle or by stimulation of the intrafusal fibers. An important point, however, is that nerve fibers labeled A to the intrafusal fibers are in a constant state of low level stimulation from the central nervous system (analogous to grid bias in vacuum tubes).

Very minute intensity of stretch will excite the annulospiral endings. When the annulospiral endings are stimulated nerve impulses arise which are transmitted to the sensory portion of the spinal cords where an immediate connection takes place to cause stimulation of the motor nerves (shown as C in Figure 15) which innervate the contractile muscle fibers comprising the main body of the muscle. Very rapid stretching of the muscle will cause marked stimulation of the annulospiral endings of the muscle spindle. This system adapts quickly and within only a few seconds it settles down to a much lower rate of impulse formation. The steady state impulses transmit information to the central nervous system, depicting the steady lengths of the muscle, while the intense instantaneous excitation transmits information depicting the rate of change of the muscle length. To express this another way, the muscle spindle responds instantaneously to phasic changes in muscle lengths but it adapts within a few seconds, and its degree of stimulation thereafter is determined by the static length of the muscle. Thus we see the analogy of a strain gauge built within the muscles in a specialized organ called the muscle spindle.

When muscles are stretched, information is immediately transmitted from the muscle spindles to the spinal cord and in addition to making connections with the motor nerves which return to the muscle itself, connections are also made to nerve fibers which traverse upwards in the spinal cord to the cerebellum. This information is used to help control the damping that prevents "overshoot" of muscular contraction and keeps the different muscular contractions throughout the body coordinated.

It was pointed out above that there is a specialized set of motor nerves which innervate the muscle fibers within the muscle spindle. Stimulation of these nerves causes contraction of the ends of the intrafusal fibers of the muscle spindles, stretching the central portion of the spindles where the sensory nerve receptors attach. Because of this, stimulation of the muscle fibers within the muscles spindle increases the number of impulses transmitted from the muscle spindle, conversely, reduction in a degree of stimulation of the spindles of the fibers within the muscle spindles reduces the excitability of the muscle spindle.

All normal muscular reactions and reflexes are superimposed on the background of the stretch reflex. This means that other activation arriving at the motor neurons finds them in a condition appropriate to the external mechanical load, and the requirements for control of muscular action are thus delegated to a very simple reflex pathway which, by its speed of action, can coordinate muscular action to produce the same movement when a wide range of different conditions of resistance are encountered.

Engineers speak of a "servo" system, or a mechanism designed to keep the action constant; for example, a centrifugal governor controls an engine to run at constant speed with changing loads by regulating the throttle. The centrifugal governor imitates a sense organ and a throttle valve, the motor neurons, and the feedback of information about the action to the controlling mechanism is the essential feature. Thus the simple proprioceptive reflex is present under all normal conditions, and other reflexes blend with it to produce action related to the mechanical reaction met within the movement. When muscle groups are called upon to do work the stretch reflex mechanism provides knowledge of the level of effort required to continue the work.

A large portion of the muscle masses of the body is concerned with maintaining posture against the force of gravity. To perform useful mechanical work, it is necessary to sense the extent of the gravitational force against which the work is being performed, and also to sense the relative positions of the articulated skeletal structures which form the mechanical means for accomplishing motion and thereby useful work. It is easy to see how the useful purpose provided by the stretch reflex may be altered and indeed perverted when the neuromuscular system is no longer faced with performing useful work against the force of gravity.

We have used this illustration to describe an interesting and exquisitely sensitive neuromuscular mechanism. The reduction in muscular effort required to work and live in the null gravity environment may set the stage for loss of muscle strength through disuse. Disuse atrophy in the muscles might well be viewed as another form of physiological "deconditioning" about which we have very little information.

VESTIBULAR SENSATIONS AND THE MAINTENANCE OF EQUILIBRIUM

Equilibrium is controlled especially by the vestibular apparatuses, though other mechanisms, including vision and proprioceptive impulses from the limbs, aid in its control. Equilibrium is maintained by automatic shift of tone in the muscles from one side of the body to the other side or forward and backward in accordance with various signals arriving from the vestibular apparatus, the eyes, and the proprioceptors. These signals apprise the central nervous system of the position of the body with respect to gravity and with respect to other forces. It is quite appropriate that the vestibular apparatus, which is the most important organ of equilibrium, is located in close approximation to other neural control centers in the brain stem.

VESTIBULAR APPARATUS

The membranous labyrinth is composed mainly of the cochlear duct, the three semicircular canals, and two large chambers known as the utricle and the saccule (see Figure 16). The cochlear duct is concerned with hearing and has nothing to do with the function of equilibrium; the saccule is concerned with hearing in some lower animals but probably is nonfunctional in the human being; however, the utricle and the semicircular canal are especially important for maintaining equilibrium and are collectively called the vestibular apparatus.

THE UTRICLE

Located in the utricle is the macula, which is covered by a gelatinous layer in which many small bony masses known as otoconia are embedded (Figure 17). Also in the macula are many hair cells, which project hair tufts up into the

ARRANGEMENT OF CIRCULAR CANALS

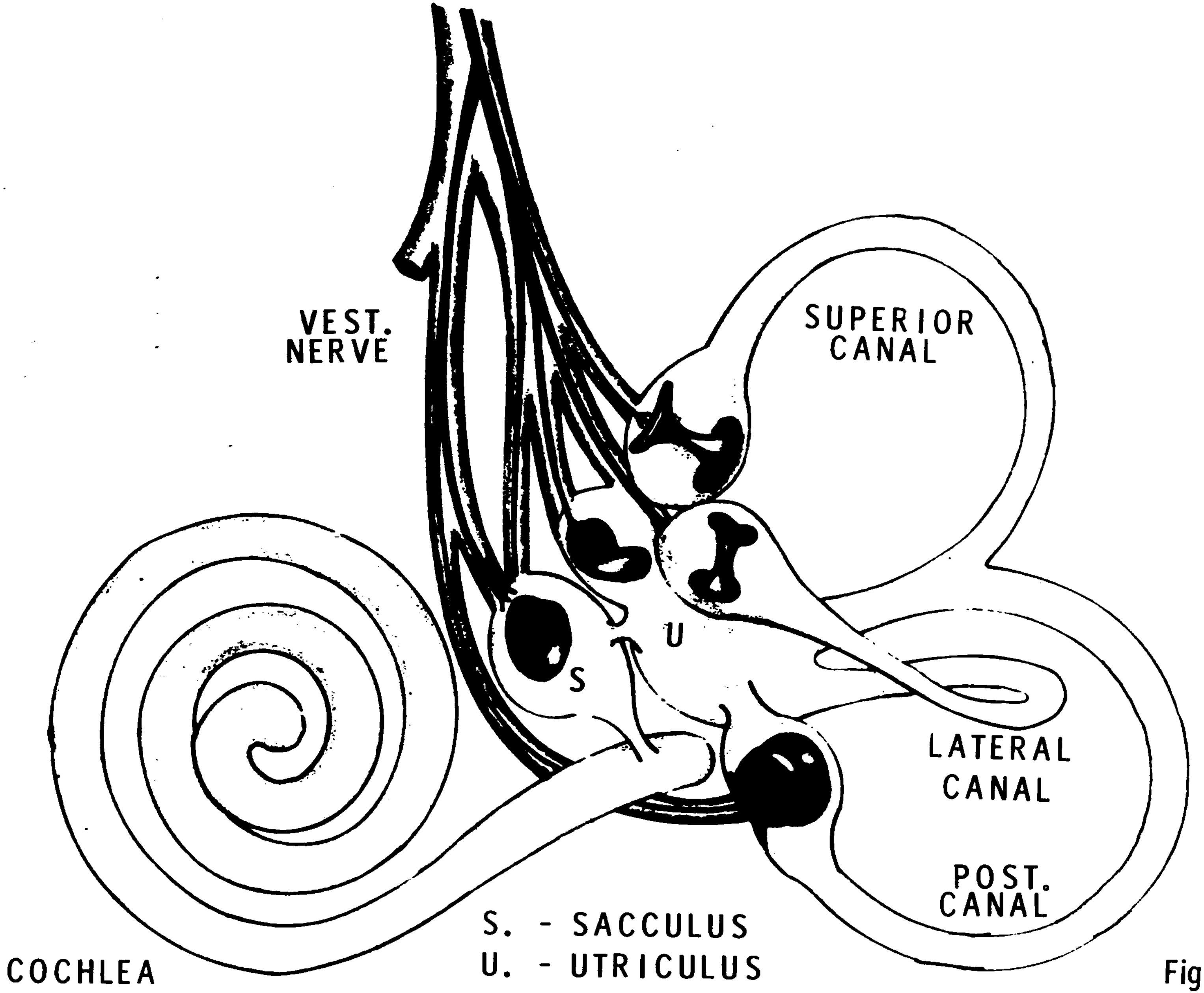

Figure 16

STRUCTURE OF A MACULA

STRUCTURE OF A MACULA (SCHEMATIC):
O. -Otoconia; G. -Gelatinous Layer; H. T. -Hair Tufts; H. -Hair Cells;

S. -Supporting Cells; B. M. -Basilar Membrane; N. -Nerve Fibers

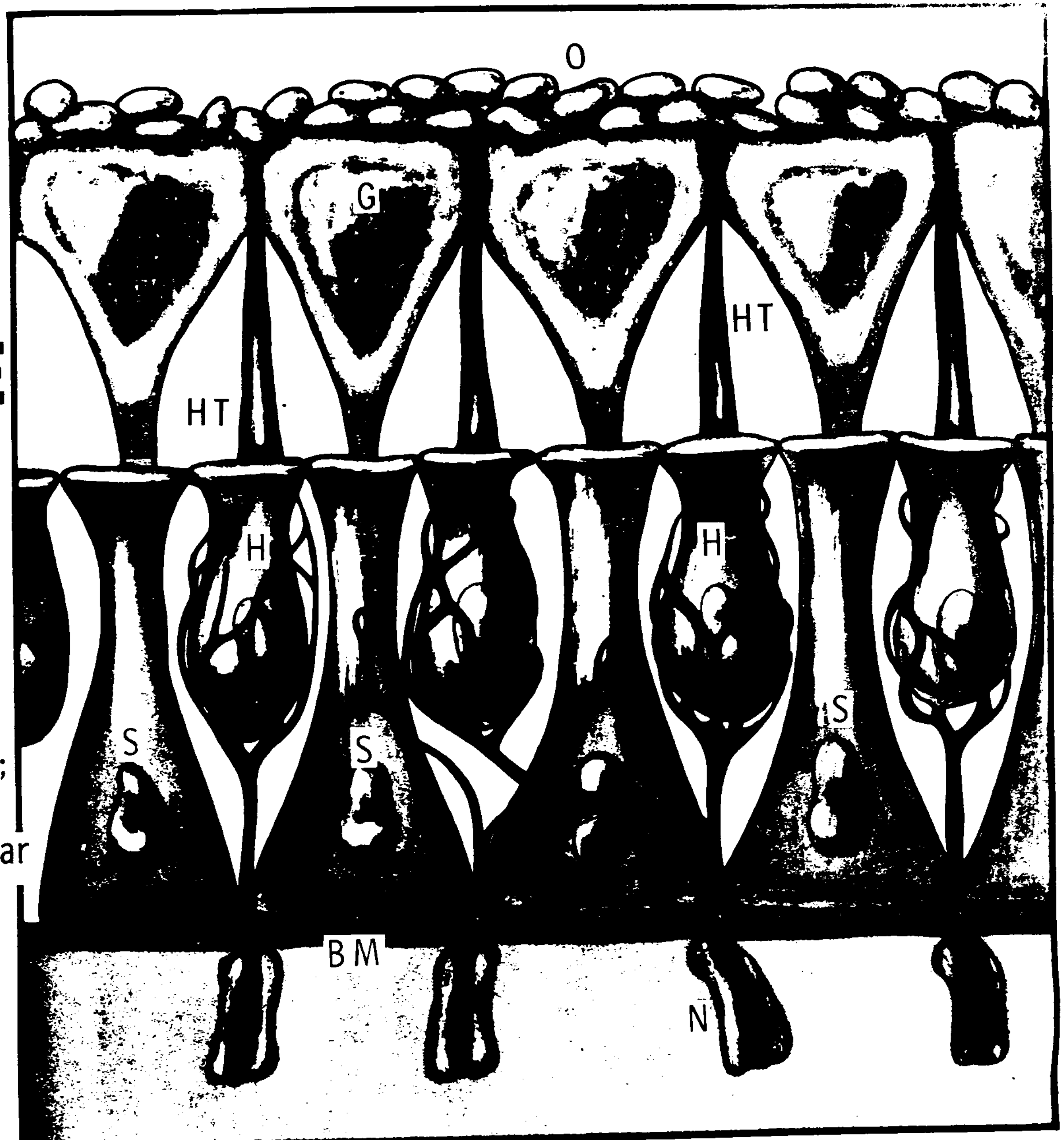

Figure 17

gelatinous layer. Around these hair cells are entwined sensory axons of the vestibular nerve, so that bending the hair tufts to one side transmits impulses to apprise the central nervous system of the relative position of the otoconia in the gelatinous mass over the macula. Therefore, it is the weight of the otoconia compressing the hair tufts that provides signals from the utricle, and these signals in turn are transmitted by appropriate nerve tracts to the brain, thence controlling equilibrium.

THE SEMICIRCULAR CANALS

In the ampullae of the semicircular canals are small crests, each called a crista ampullaris, and on top of the crest is another gelatinous mass known as the cupula (Figure 18). Into the cupula are projected hair tufts from hair cells in the ampullary crest and these hair cells in turn are connected to sensory nerve fibers that pass into the vestibular nerve. Bending the cupula to one side or the other stimulates the hair cells and sends appropriate signals through the vestibular nerve to apprise the central nervous system of fluid movement in the respective canal.

The three semicircular canals in each vestibular apparatus, known respectively as the superior, the posterior, and the lateral semicircular canals, are arranged at right angles to each other so that they represent all three planes in space (Figures 19 and 20). When the head is bent forward at approximately 30°, the two lateral semicircular canals are located approximately horizontal with respect to the surface of the earth. The superior canals are then located in vertical planes that project forward and 45° outward, and the posterior canals are also in vertical planes but project backward and 45° outward. Thus the superior canal on each side of the head is in a plane parallel to that of the posterior canal on the opposite side of the head, whereas the two lateral canals on the two sides are located in approximately the same plane.

FUNCTION OF THE UTRICLE IN THE MAINTENANCE OF STATIC EQUILIBRIUM

Gravitational pull on the otoconia causes them to press continually on the macular hair tufts in the utricles, and this constantly apprises the central nervous system of the position of the head with respect to the direction of gravitational pull. The density of the otoconia is almost three times that of the surrounding fluid and tissues, and because of this they bend the hair tufts forward when the head leans forward. Likewise, leaning the head to one side bends the hair tufts in that same direction.

STRUCTURE OF A CRISTA

STRUCTURE OF A CRISTA (SCHEMATIC):
G. -Gelatinous Substance; H. -Hair Cells; S. - Supporting Cells; H. T. - Hair Tufts; N. - Nerve Fiber

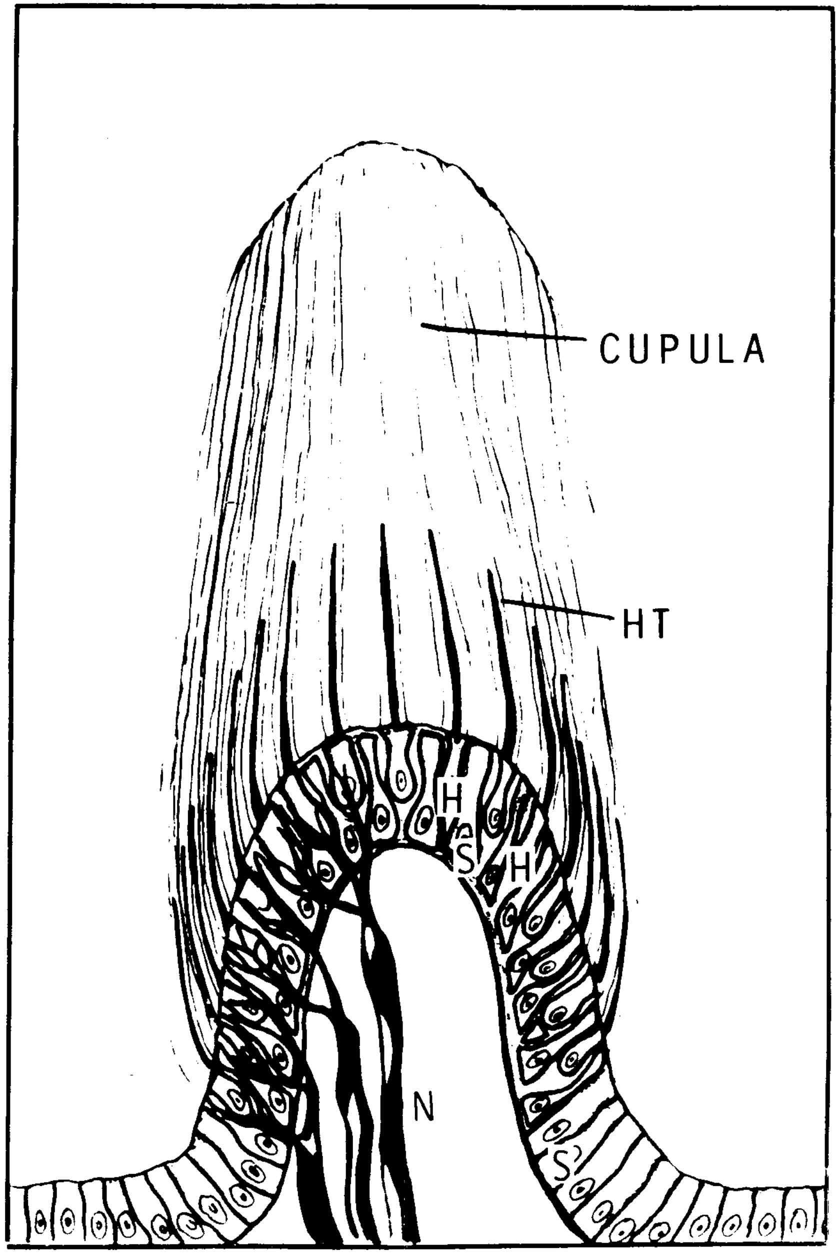

Figure 18

THE VESTIBULAR APPARATUS

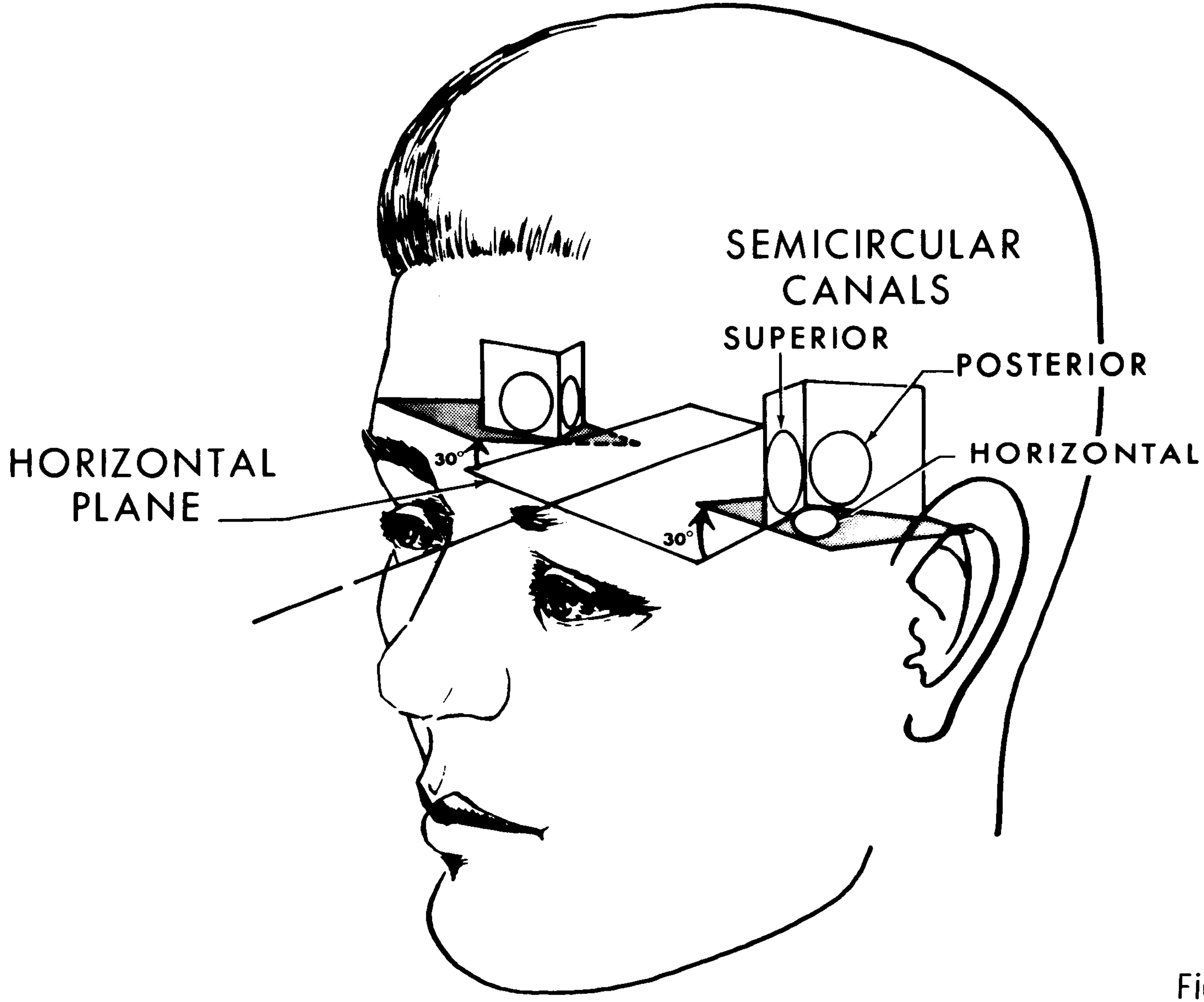

Figure 19

ANATOMY OF THE VESTIBULAR APPARATUS

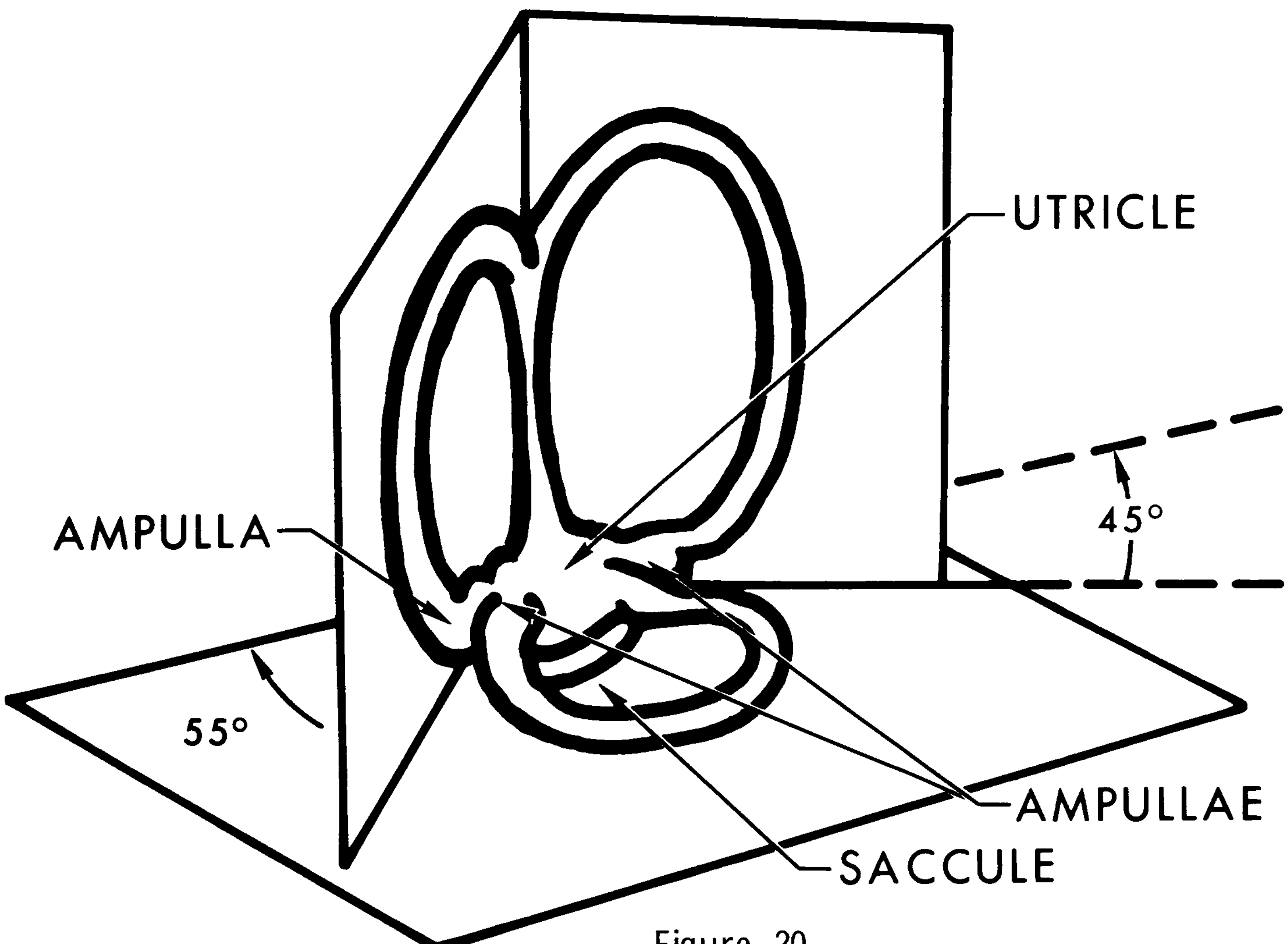

Figure 20

It is especially important that the different hair cells are oriented in several different directions in the maculae so that at different positions of the head, different ones of the hair cells become stimulated. The "patterns" of stimulation of the different hair cells apprise the nervous system of the position of the head with respect to the pull of gravity. This mechanism along with nervous connections in the brain and in the spinal cord reflexly excite the appropriate muscles to attain proper equilibrium. Very little is known about the actual mechanism by which the hair cells are stimulated except that bending the hair in the proper direction causes the cell to transmit a continual series of impulses. If the hair is bent in one direction, the rate of impulses increases, whereas, if the hair is bent in the opposite direction, the rate of impulses decreases.

DETECTION OF LINEAR ACCELERATION BY THE UTRICLE

When the body is suddenly thrust forward, the otoconia, which have greater inertia than the surrounding fluids, fall backward on the hair tufts, and information of mal-equilibrium is sent into the nervous centers, causing the individual to feel as if he were falling backward. This automatically causes him to lean his body forward; the forward lean then shifts the otoconia anterially or forward, that is. Thus, the body automatically leans farther and farther forward until the anterior shift of the otoconia exactly equals the tendency for the otoconia to fall backward because of the linear acceleration. At this point, the nervous system detects a sense of equilibrium and therefore shifts the body no further forward. As long as the degree of linear acceleration remains constant and the body is maintained in that forward leaning position, the person will fall neither forward nor backward. Thus, the otoconia operate to maintain equilibrium during linear acceleration in exactly the same manner as they operate in static equilibrium.

If a person in an airplane goes around and around in a deep bank, centrifugal force will push him against the seat of the plane. This force, like gravity, also presses the otoconia downward against the hair tufts in the utricles. Therefore, the centrifugal force is perceived in exactly the same manner as either gravitational or linear acceleratory forces, and, if the person were standing up in the airplane, it would still be the utricles that would control the necessary equilibrium adjustments of his postural muscles.

THE SEMICIRCULAR CANALS AND THEIR DETECTION OF ANGULAR ACCELERATION

When the head suddenly begins to rotate in any direction, the endolymph in the membranous semicircular canals,because of its inertia, tends to remain stationary while the semicircular canals themselves turn. This causes relative fluid flow in the canals in a direction opposite to the rotation of the head. In each ampulla of the semicircular canal resides the cupule and its embedded hair cells and which bend in the direction of fluid movement. Nerves arising from the ampulla are stimulated when there is relative motion between the walls of the semicircular canal and the fluid contained therein; however, once a steady state of rotation has been achieved, within a few seconds the semicircular canals no longer emit any impulses. In summary then, the semicircular canals detect the rate of change of rotation, or angular acceleration.

The angular acceleration required to stimulate the semicircular canals in the human being varies from 0.2° per second per second, up to as high as 2° per second per second, or an average of about 1° per second per second. In other words, when one begins to rotate, his velocity of rotation must be as much as 1° per second by the end of the first second; 2° by the end of the second second, 3° per second by the end of the third second, and so forth in order for him barely to detect that he is beginning to rotate.

THE "PREDICTIVE" FUNCTION OF THE SEMICIRCULAR CANALS IN THE MAINTENANCE OF EQUILIBRIUM

Since the semicircular canals do not detect that the body is off balance in the forward direction, in the side direction, or in the backward direction, one might at first ask, what is the function of the semicircular canals in the maintenance of equilibrium? All they detect is that the person's head is beginning to rotate or to stop rotating in one direction or another. The function of the semicircular canals therefore could not possibly be to maintain static equilibrium nor to maintain equilibrium during linear acceleration or when the person is exposed to steady centrifugal forces. Yet, it is well known that loss of function of the semicircular canals causes a person to have very poor equilibrium, especially when he is performing rapid and intricate body movements. We can perhaps explain the function of the semicircular canals best by the following illustration. If a person is running forward very rapidly and then suddenly begins to turn to one side, he will fall off balance a second or so later unless appropriate corrections are made ahead of time. But unfortunately, the utricle will not detect that he is off balance until after this has occurred. On the other hand, the semicircular canals will have already detected that the person is beginning to turn, and this information can easily apprise the central nervous system of the fact that the person will fall off balance within the next second or so unless some correction is made. In other words, the semicircular canals predict ahead of time that mal-equilibrium is going to occur even before it occurs and thereby cause the equilibrium centers to make appropriate adjustments. In this way, the person need not fall off balance because he begins to correct the situation.

IMPORTANCE OF VISUAL INFORMATION IN THE MAINTENANCE OF EQUILIBRIUM

After complete destruction of the vestibular apparatuses, and even after loss of most proprioceptive information from the body, a person can still use his visual mechanisms to a high degree of efficiency for maintaining equilibrium. The visual images help the person maintain equilibrium simply by visual detection of the upright stance. Also, very slight linear or angular movement of the body instantaneously shifts the visual images on the retina, and this information is relayed to the equilibrium centers. In this respect the optic information is similar to that from the semicircular canals and can help the equilibrium centers predict that the person will fall off balance before this actually occurs if appropriate adjustments are not immediately made. Many persons with complete destruction of the vestibular apparatus will have almost normal equilibrium as long as their eyes are open and as long as they perform all motions very slowly. But, either in the case of very rapid movements or closure of the eyes, equilibrium is immediately lost.

NYSTAGMUS CAUSED BY STIMULATION OF THE SEMICIRCULAR CANALS

When one rotates his head, his eyes must rotate in the opposite direction if they are to remain "fixed" on any one object long enough to gain a clear image. After they have rotated far to one side, they jump suddenly in the direction of rotation of the head to "fix" on a new object and then rotate slowly backward again. This sudden jumping motion forward and then slow backward motion is known as nystagmus. The jumping motion is called the fast component of the nystagmus, and the slow movement is called the slow component.

Nystagmus always occurs automatically when the semicircular canals are stimulated. For instance, if a person's head begins to rotate to the right, backward movement of fluid in the left lateral (horizontal) canal and forward movement in the right lateral (horizontal) canal cause the eyes to move slowly to the left; thus, the slow component of nystagmus is controlled entirely by the vestibular apparatus and the appropriate centers in the brain, but when the eyes have moved as far to the left as they reasonably can, centers located in the brain stem at close approximation to the centers that control eye movement cause the eyes to jump suddenly to the right; then the vestibular apparatuses take over once more to move the eyes again slowly to the left.

We have briefly described some mechanisms that man has acquired through long evolutionary processes which permit him to live and work and move about on the surface of the earth. Space flight certainly implies a very unusual environment in which man must live, and there may be times when we must call upon occupants of spacecraft to cope with circumstances which by themselves tend to disturb normal physiological functions but which are also tolerable; that is to say, they do not threaten life. There may also be circumstances of space flight against which man may be able to do very little with his own compensations, and it is here where we find our responsibility in providing an environment which in some degree provides an artificial environment more conducive to comfort and normal physiological responses. Considerations have been given to building spacecraft in which an artificial gravity may be provided. Certain great advantages reside in this concept, for reasons which have been mentioned in this paper. In any event it is necessary for us to continue learning all we can learn about man's responses when placed in the unusual environment of space flight so that decisions can be made as to whether artificial gravity, for example, must be provided.

WATER METABOLISM AND ELECTROLYTE BALANCE

Water Metabolism

Water forms the main constituent of tissues and it moves from one area or compartment of the body to another more frequently than any other substance. It has high solvent powers, high surface tension, and high chemical reactions that involve hydrolysis and hydration. It serves as a medium by which all substances reach the tissue cells. It is necessary for absorption, diffusion, secretion, and execretion. The volume of water exchanged between the blood, tissue fluid, and cells is enormous, especially between blood and the cells forming digestive fluids; and the reabsorption of water per day in the small intestines. This fluid exchange amounts to about 8,000 liters per day.

Water Distribution in the Body

In the normal adult, 70 percent of the body weight is water. Its distribution in the adult is shown in the following diagram (Figure 21). While whole blood forms about one-twelfth of the body weight; plasma volume forms about one twenty-fourth to one twenty-fifth of body weight. Plasma volume is not a static quantity. It is the net effect between constantly varying additions and losses of the various fluid compartments which operate to some extent independently of each other.

Sources of Water

a. Ingested as water or in beverages of all kinds and in the food eaten. Some foods have a higher content of water than others.

b. Water of metabolism. An ordinary mixed diet will yield from 300 to 350 cc's of water. It has been found that 100 grams of fat yields 107 grams of water; 100 grams of starch yields 55 grams of water; 100 grams of protein yields 41 grams of water.

Water Output

Water is lost from the body through urine, perspiration, lungs, and feces. The amount lost through the skin will vary with temperature and humidity. At average room temperature there will be insensible perspiration, and during exercise or elevation of room temperature or in torrid climates, there will be increased loss of water by perspiration. When there is considerable loss of water through the skin, there will be less loss through the urine. In this instant urine would be more highly concentrated. When large quantities of water are lost through the skin, sodium chloride is excreted and must be replaced. High humidities increase water loss through the skin. Emotional states also increase water loss.

Average Water Intake (Adult Male, Moderate Activity)		Average Water Output (Aver. Room Temp. & Humid.)	
Beverages	1,350 cc's	Urine	1,500 cc's
Foods	1,000 cc's	Feces	150 cc's
Water of Oxidation	350 cc's	Skin	700 cc's
		Respiration	350 cc's
Total	2,700 cc's		2,700 cc's

DISTRIBUTION OF BODY WATER

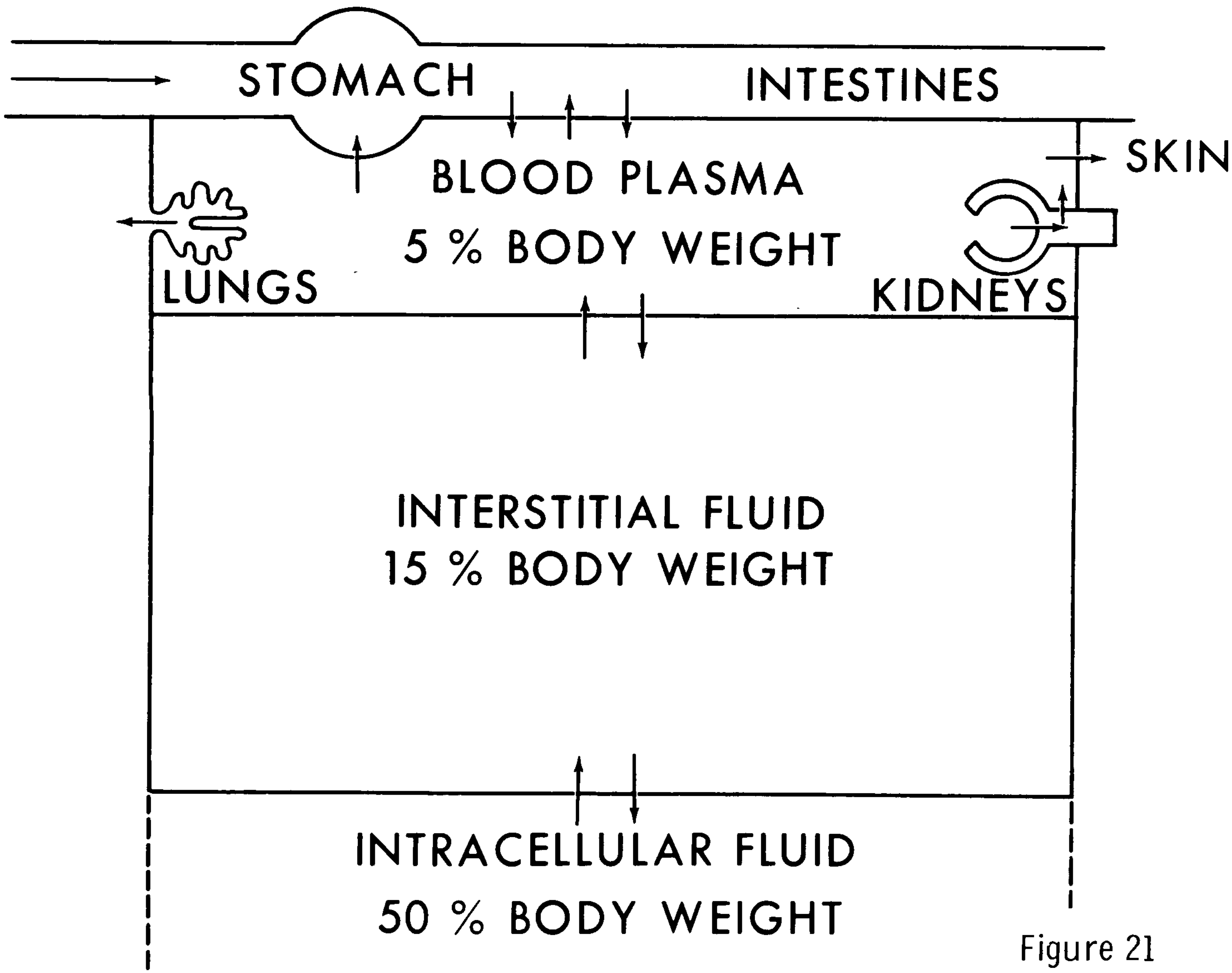

Figure 21

Some of the conditions that disturb water balance are diarrhea, vomiting, diabetic acidosis, or acute disturbances of the adrenal cortex. In these instances, loss of electrolytes is greater than loss of water. If insufficient fluid is taken, or in diabetes insipidous, a condition which leads to grossly increased inhibition of water or in excessive perspiration, the loss of water is greater than the loss of electrolytes.

In fasting, there is corresponding depletion of water and electrolytes; in edema, both water and electrolytes are retained. If the kidney fails to eliminate water, as in certain diseases, water intoxication with widespread physiological implications results. This is evidenced by increased blood volume, perhaps a rise in blood pressure, an increase in body weight, and a variety of other symptoms.

The Regulation of Water Metabolism

Since the amount of water in the body must be kept constant within narrow limits, it is important that fluids be replaced and electrolyte balance be maintained. Normally this replacement is accomplished in the small intestines through the absorption of fluids and electrolytes taken in the diet. Thirst may be the result of decrease in body fluids due to loss through any channel, such as excessive perspiration, excessive urine formation, diarrhea, or others. It is caused by general body dehydration or by drying of the tissues of the mouth and pharynx. It is also believed that when the mouth cells are dry, nerve endings in the mouth are stimulated and send impulses to nerve centers which create the sensation of thirst. Specialized structures in the brain regulate the amount of water that is absorbed in the kidney tubule. The adrenal cortex regulates the reabsorption of sodium, potassium, and chloride in the kidney tubule, thus maintaining the balance of these electrolytes which are necessary for water balance. Blood plasma and interstitial fluid are almost identical in ionic composition.

Intracellular fluid contains chiefly potassium; magnesium; phosphate, bicarbonate, and sulfate ions. Protein concentration is very high. The relative amounts of non-electrolytes is small. These include amino acids, glucose, other nutritive substances, and the products of metabolism.

In the red blood corpuscle, bicarbonate and chloride ions predominate and very little phosphate is present. In muscle cells, phosphates predominate and bicarbonate ions are present in small amounts, while chloride ion is almost completely absent. All cells contain potassium in large quantities and sodium in small quantities.

It is not understood why the electrolytes are distributed in this manner or what forces hold them in the compartments.

If one compares the qualitative ionic composition of plasma with that of sea water, the similarity is immediately apparent. However, the ions in sea water are more concentrated than in plasma, lending some credence to the theory that when terrestrial animals evolved, they enveloped within their vascular systems an ionic environment similar to sea water. Regulation of this plasma ionic balance was initiated by natural selection.

The naturally occurring ionic constituents in sea water increased in relative concentration by the very slow process of leaching out of salts from terrestrial formations and subsequent deposition of these salts in the sea.

The adrenal cortex hormone functions in maintaining potassium and sodium chloride equilibrium by controlling the excretion of these ions by the kidney. The potassium in cells appears to be related to growth and metabolism of cells. It promotes alkalinity and helps to maintain osmotic characteristics of blood. Sodium increases cell permeability to water, holds water in the tissues, and serves as a base for alkaline salts. Calcium is a constituent of all body fluids, is concerned with cell permeabilities, and decreases cell permeability to water. It forms alkaline salts. Chlorine is found in all body fluids and functions in the acidbase equilibria in water balance.

The compartments of water remain comparatively stable in relation to quantity and quality. The transfer of water between the compartments is controlled in part by electrolyte balance, by physical forces, by osmotic concentrations, and by pressures, i.e., effective hydrostatic pressures and the oncotic pressure of proteins.

Regulation of Water Loads

When fluid load of the body is markedly increased by intake of excessive amounts of fluid in a comparatively short period of time, many adjustments are necessary. For instance, when one to 1.5 liters of fluid are taken with no food, absorption is complete in from 30 to 45 minutes. Blood volume may be increased and cardiac output is temporarily increased; blood may or may not be diluted. The adjustments are made rapidly; the capillaries open, hence capillary beds are increased; the sinusoids, the spleen, lungs, and liver open to hold more blood; and water is transferred to interstitial compartments.

The balance is chiefly restored by the kidney and excess water is eliminated within 2 or 3 hours. This is accomplished by the physical laws of diffusion, effective hydrostatic pressures, electrolytes and hormone action.

SOURCES OF IONS

Sources of ions in the body are from the metabolic activities in cells and from foods. Some of them are constituents of acids, bases, and salts in the food. Others are made in the cells as products of metabolism. Some of these are normal constituents of the body fluids, others predominate in cells. It is evident that some of the ions in the body are present in mere traces, others in small quantities, and still others in larger amounts.

Electrolytes which function in maintaining the composition of blood plasma include:

Acid Ions	(mEq/L)	Base Ions	(mEq/L)
HCO_3^-	27	Na^+	142
CI^-	103	K^+	5
HPO_4^{--}	2	Ca^{++}	5
SO_4^{--}	1	Mg^{++}	3
Organic Acid	6		
Protein	16		
TOTAL	155		155

All of the ions must be kept constant in composition within narrow limits, as the normal range of blood is pH 7.3 to pH 7.5. Homeostasis is maintained by buffer systems in blood, lymph, tissue fluids, and in cells.

ACIDOSIS

In blood, if the hydrogen-ion concentration exceeds a pH 7.4, a condition known as acidosis results. This may occur in severe diabetes or starvation as a result of disturbance of glucose and fat metabolism and the consequent accumulation of acetoacetic acid in the body fluids. Acidosis may also occur from other causes, such as excessive loss of alkali ions, such as sodium and potassium salts, as in severe diarrhea or prolonged vomiting. This depletes the blood of essential ions.

ALKALOSIS

Alkalosis is a decrease in hydrogen-ion concentration below pH 7.5. This indicates an increase in hydroxyl-ion concentration above the normal limit of pH 6.5. It may be caused by the ingestion of excessive amounts of sodium bicarbonate or loss of chloride ion by prolonged vomiting and by hyperventilation with excessive loss in carbon dioxide.

THE ROLE OF THE KIDNEY IN MAINTAINING HOMEOSTASIS OF BODY FLUIDS

Many years ago a famous physiologist, Claude Bernard, said: "All vital mechanisms, however varied these may be, have but one object, the maintenance of the constancy of the conditions appropriate for life in the milieu interieur." Another physiologist put it this way, "In the last analysis, the composition of the 'milieu interieur' is determined not by what the body takes in, but by what is retained and what is excreted." What the kidney does most rigorously is to maintain the constancy of the internal environment, by eliminating the products of cell metabolism - such as nitrogenous and hormonal substances, toxic substances, organic acids, and inorganic substances.

The kidney helps to regulate water metabolism, which is essential for water balance. Plasma volume and water content are also regulated by the kidney. When more water is ingested than is needed by the body, the kidney promptly eliminates it as dilute urine. Or when insufficient water is ingested, or when large quantities are lost through perspiration, diarrhea or vomiting, the kidney eliminates a smaller amount of more concentrated urine. The kidney eliminates inorganic ions such as sodium, potassium, chloride, calcium, phosphate, sulfate, magnesium, and others, in relation to concentrations and needs of the body. In this way the kidney regulates the osmotic equilibrium and ionic balance in plasma. The kidney helps to regulate the acid base balance of the body by eliminating excess of potential acid ions such as phosphate and sulfate and the hydrogen ions. In this way the urine may be more or less alkaline or acid in relation to blood pH.

When nonvolatile acids are produced in the body, the kidney forms ammonia and hence spares the inorganic base of the blood. By exchange of ions, the kidney converts the dibasic phosphates to the monobasic phosphates and in this way returns sodium bicarbonate to the body's store of alkaline reserve. The expression alkaline reserve refers to the potassium and sodium salts available for buffer action in the blood plasma at any particular time.

How the Kidney Does Its Work--Urine Formation

The kidney consists of thousands of discrete capillary beds, called glomeruli, each surrounded by a collecting capsule. As blood flows through the glomeruli, a dilute, protein-free fluid is filtered into the glomerular capsule. This means that the glomerular membrane is impermeable to protein and that capsule fluid is the same as plasma fluid, minus the proteins.

The filtration is mainly a physical process which is related to the blood pressure within the glomerular capillaries, the condition of the membranes, and the nature of the blood plasma. It has been estimated that nearly 600 quarts of blood pass through the two million or more glomeruli of the kidney each day.

The Work of the Tubules

The protein-free filtrate passes from the glomerular capsule through tubules leading to the urinary bladder. But reabsorption of both water and solutes takes place along the tubules, which are surrounded by a network of blood capillaries. Certain substances have great value to the body and must be retained despite the filtration which takes place in the kidney; therefore, these substances are reabsorbed, and such products as glucose, chlorine, sodium, potassium, and amino acids are selectively returned to the blood. These substances are either absent in urine or present in urine in low concentrations.

Certain substances may be viewed as waste products to the body. These include urea, uric acid, sulfates, and phosphates and are reabsorbed in variable amounts. Hence, the concentration of these substances is high in urine. After selective reabsorption takes place, the filtrate becomes concentrated by additional absorption of water from the tubular fluid, acidified, and takes on the characteristics of urine. The whole process is physically, chemically, and hormonely controlled.

Rate of Urine Formation

Experiments have shown that the glomerular filtration rate is usually about 120 to 125 cc's per minute and that urine output approximates 1 cc per minute, or about 1,500 cc's per day. This means that the kidney must filter about 170 liters of fluid and reabsorb 168 to 169 liters of water per day, containing about 170 grams of glucose, 1,000 grams of sodium chloride, and 360 grams of sodium bicarbonate. This work is accomplished by some two million secretory units.

It has been estimated that blood flow through the kidney is about 1,300 cc's per minute, or about one-fifth of the cardiac output per minute. Since the two kidneys weigh about 300 grams, this means that the blood flow through the kidney is about 4 cc's per gram of renal tissue per minute of time.

ENDOCRINE CONTROL OF TUBULAR FUNCTION

Water reabsorption in the tubules is an active process which is regulated by the antidiuretic hormone (ADH) of the posterior pituitary, a glandular organ located in the brain. In turn, it is believed that the secretion of ADH is controlled by still another element of the brain, the hypothalamus. The thyroid glands and the outer shell of the adrenal gland, the adrenal cortex, are also concerned with this process as removal of these glands cause disturbances in renal function. The adrenal cortex controls the reabsorption of potassium, sodium, and chloride in the kidney tubules.

The foregoing discussion is meant to orient the reader toward two important ideas; namely, (1) the kidneys handle an enormous amount of blood flow and produce an enormous quantity of filtrate, the majority of which is reabsorbed and returned to the blood. Selective reabsorption of certain produces and constituents of the plasma which have value in maintaining homeostasis are thereby conserved by processes to a very large extent under hormonal control, and (2) the kidneys constitute the principle end organ in the complex of processes concerned with the regulation of total body water. Because the kidneys regulate the amount of water in the plasma, it follows that the kidney is able to regulate the amount of water in the cells of the body, since there must always be an osmotic equilibrium established between the plasma and the solutions which comprise the interior of the cell. If any of the several stresses of space flight serve to disturb the quantities or distribution of circulating fluid volumes, it follows that knowledge of the output and composition urine would provide further data on the extent of the stress of space flight.

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APPENDIX C

THE QUESTION OF ARTIFICIAL GRAVITY

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THE QUESTION OF ARTIFICIAL GRAVITY

The creation of an artificial gravity environment in manned space flight systems has often been proposed as a means of preventing physiological deconditioning, improving habitability and preserving astronaut work effectiveness.

From a physiological standpoint, postulated benefits lie primarily in the realm of maintaining physical fitness. For example, the rate and extent of cardiovascular deconditioning could be reduced, musculoskeletal degradation could be suppressed and vestibular atrophy could be prevented.

From the standpoint of habitability, many astronaut activities could be greatly simplified. For example, assembly and repair, traction and locomotion, eating and drinking, micturition and defecation could be facilitated greatly by the presence of an inertial force. Sanitation could also be easier to maintain if dirt and fluids tend to collect on the floor, and circulation of space cabin atmospheres could be better controlled if convection currents exist.

Gravity fields can be approximated in space by centrifugal forces created by rotating the entire spacecraft, or parts of it, as in the case of an onboard centrifuge. Spacecraft spinning could be effective for minimizing some of the physiological and habitability problems introduced by weightlessness. Conversely, the usefulness of a small onboard centrifuge appears to be limited to the roles of a research tool and a physiological reconditioning device helpful in rehabilitating the crew to gravity forces prior to re-entry and following prolonged exposure to weightlessness. Both of these modes of artificial gravity, however, introduce secondary problems which, in some instances, could be more severe than the weightlessness effects they are intended to overcome (Ref. 1). Tables 1 and 2 summarize some advantages and disadvantages of weightlessness and artificial gravity as candidate operational modes.

Present flight evidence suggests that man should be able to endure prolonged space flight and perform satisfactorily under conditions of weightlessness. In fact, man's ability to survive weightlessness is less worrysome than his ability to cope with re-entry and post-landing stresses.

TABLE 1-A

ZERO-G VERSUS ARTIFICIAL-G TRADEOFFS

I. ZERO GRAVITY: *

ADVANTAGES	DISADVANTAGES
Behavioral: • Sub-nominal vehicle volumes are better endured. Man-Machine Interfaces: • Suit donning and doffing is facilitated. • Working in cramped quarters is less difficult. • Inconveniently located work-sites are more accessible. • Certain manual tasks become easier (e.g. handling large or heavy objects). Systems: • Fire spread is slow because convection currents are lacking.	Physiological: • Unrestrained IVA can invoke motion sickness symptoms (habituation appears possible). • Vestibular, cardiovascular, and musculoskeletal systems might degrade during extended flights. • Other physiological systems may in time be affected. Behavioral: • Normal habitability patterns are partially changed (e.g. locomotion, meal preparation and eating, waste products excretion). Man-Machine Interfaces: • Manual tasks require restraints for body positioning. Systems: • All systems must be designed, tested and qualified for 0-g operation. • Liquids behave unconventionally and spillage could become a problem.

* Zero-g experience exists.

TABLE 1-B

ZERO-G VERSUS ARTIFICIAL-G TRADEOFFS (CONT'D)

II. ARTIFICIAL GRAVITY:*

ADVANTAGES	DISADVANTAGES
Physiological:	Physiological:
•Depending on g strength, cardiovascular and musculoskeletal degradation can be reduced.	•Bizarre vestibular sensations may be experienced.
Behavioral:	•Gravity gradient effects in the cardiovascular and musculoskeletal systems might occur during prolonged missions.
•Habitability patterns are generally normal.	•The crew must be protected from excessive rotational perturbations (e.g. wobble).
•Body restraints are not required for manual tasks.	•Frequent crew transfers between a rotating vehicle and its non-rotating hub may not be possible physiologically.
•Personal hygiene, meal preparation and waste management systems work better than in zero-g.	Man-Machine Interfaces:
	•Coriolis accelerations may interfere with the performance of manual tasks.
	•Body weight is motion dependent.
	•The dynamics of free falling objects can be unusual.
	•EVA during vehicle spin is precluded by crew safety requirements.

* Artificial-g experience does not exist.

TABLE 1-C

ZERO-G VERSUS ARTIFICIAL-G TRADEOFFS (CONT'D)

II. ARTIFICIAL GRAVITY *

ADVANTAGES	DISADVANTAGES
	Experiments: • Biological and materials technology experiments which require zero-gravity must be isolated from spacecraft rotation. • All experiments involving pointing (e.g. astronomy and earth resources) require compensation for rotational motion and wobble. Systems: • Docking and undocking operations are complex. • Systems may have to be qualified for both zero-g and artificial-g environments.

* Artificial-g experience does not exist.

TABLE 2-A

IMPACT OF ZERO-G AND ARTIFICIAL-G ON S/C SYSTEMS AND SPACE OPERATIONS

	ZERO-G	ARTIFICIAL-G
SYSTEMS DESIGN	Systems: • All systems must be designed for 0-g operation. Man-Machine Interfaces: • Body restraints and special work tools are required for the performance of manual tasks. • Lack of preferential body orientation opens a new dimension in architectural design.	Systems: • A countermass system will be required if spinning is to be accomplished in a tethered mode. • Systems must be provided to spin and de-spin the orbital assembly. • Critical subsystems may have to be designed for both 0-g and artificial-g environments. • New engineering provisions are required for: (a) Docking and undocking operations (b) Experiments demanding target tracking (c) Experiments demanding weightlessness (d) Extravehicular activities (e) Solar panels demanding sun pointing (f) Aborts during rotational emergencies (g) Pointing communications antennas • Systems must be designed to sense and correct rotational perturbations. • Coriolis effects on all rotating equipment must be considered. • The effect of centrifugal forces and dynamics of wobble on structural design must be considered.

TABLE 2-B

IMPACT OF ZERO-G AND ARTIFICIAL-G ON S/C SYSTEMS AND SPACE OPERATIONS

CONT'D

	ZERO-G	ARTIFICIAL-G
SYSTEMS DESIGN (Cont'd.)		Systems: • Methods for transferring electrical power, water, air, cargo and men between a non-rotating hub and the spinning spacecraft must be designed. Man-Machine Interfaces: • Best work-site orientations and crew quarters layouts must be determined so that bizarre vestibular stimulations are minimized. • Best orientation and inclination of ladders and other mobility aids must be established so that Coriolis interference is minimized. • Optimum angular velocity, gravity level and vehicle radius limits must be determined so that habitability, task performance, and medical problems are eliminated or minimized.

Consequently, the implementation of artificial gravity systems cannot be justified on a physiological basis, at least not until future findings dictate a need.

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TABLE 2-C

IMPACT OF ZERO-G AND ARTIFICIAL-G ON S/C SYSTEMS AND SPACE OPERATIONS

CONT'D

	ZERO-G	ARTIFICIAL-G
SYSTEMS FABRICATION AND TESTING	Systems: •Qualification of all systems for zero-g operations as well as for launch forces is mandatory. •All systems must be man-rated for safety.	Systems: •Qualification of critical systems to zero-g operations also is highly desirable (maintenance or repair requirements may arise from time to time demanding a non-rotating mode). •All systems must be man-rated for safety.
IN-FLIGHT OPERATIONS	Physiological: •Physiological effects of prolonged zero-g exposure are presently unknown. •An initial period for in-flight accommodation must be allowed for some individuals. Behavioral: •Psychological acceptability of zero-g environment during prolonged exposure is presently uncertain. •Crew training is required pre-flight.	Man-Machine Interfaces: •Operational limits for artificial gravity environments are presently uncertain. Behavioral: •Psychological acceptability of rotating environments during prolonged exposure is presently uncertain. •Crew training is required pre-flight. Physiological: •An initial period for in-flight accommodation must be allowed for some individuals.

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From: Dr. L.F. Dietlein (MSC/DA), B.A. Gropper
Dr. W.E. Hull (MSC/DA), A.N. Kontaratos,
R.S. Mach, R.E. McGaughy

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